AN AUTOMATED SURVEY METHOD FOR ENVIRONMENTAL MONITORING AND ASSESSMENT

By

RODNEY G. HANDY

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1995

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere appreciation for the financial support of the Department of Energy's Health Physics Faculty Research Award Program. Without this award to the Department of Environmental Engineering Sciences at the University of Florida, this research, the dissertation, the numerous technical publications/presentations, and my advanced degree, would not have been possible. Secondly, I would like to thank the individuals at ORISE for their technical support on this project. Thirdly, I would like to thank Dr. W. Emmett Bolch and the rest of the committee (Dr. Eric Allen, Dr. William Properzio, Dr. Tom Crisman, and Dr. Bon Dewitt) for their technical expertise and mentoring during the course of this research. Next, I would like to thank Mr. Michael Lafreniere for his programming support, which was critical to the success of this project. And finally, I would like to thank my wife, Mary, and my three children, Blair, Emily, and Willie, for their patience, understanding, and love over the past five years.

TABLE OF CONTENTS

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

AN AUTOMATED SURVEY METHOD
FOR ENVIRONMENTAL MONITORING
AND ASSESSMENT

By

Rodney G. Handy

May 1995

Chairperson: Dr. W. Emmett Bolch
Major Department: Environmental Engineering Sciences

Radiological surveys are a time-consuming component of the total decommissioning process. Manual gridding is the common and accepted method currently used by survey teams to give spatial significance to the measured levels of radiation found during on-site surveys. However, the gridding process requires substantial man-hours of labor and is not conducive to real-time data analysis and assessment. In addition, several technical forms pertaining to the results acquired during the survey must be completed manually as a part of the final decommissioning report.

The purpose of this research was to develop an automated, computer-based system of performing radiological surveys. A special emphasis was placed on designing the unit for indoor operations. The system was used to determine the spatial data atomatically,

thus eliminating the need for manual gridding or manual calculations.

Five positioning techniques (i.e., ultrasonic positioning, mouse-traverse ranging, laser positioning, inertial navigation positioning, and global positioning) were evaluated for cost-effectiveness, accuracy, applicability, and overall merit. The two most cost-effective techniques were determined to be ultrasonic positioning and mouse-traverse positioning. These two techniques were coupled, via computer hardware and software, with the necessary detection instrumentation to make up a totally integrated field survey system.

The two methodologies have been tested under different circumstances in the field. The most noteworthy application came about recently during the characterization survey of several formerly utilized radiochemical instrumentation laboratories. The two automated techniques provided accurate spatial data for approximately twice as many data points in about 40 percent the time required to perform the survey manually. However, it was determined that the initial costs, lack of ruggedness, and range limitations were the major drawbacks to the automated approach.

In summary, a technique for providing automated positioning to the survey process was elucidated. The integrated system, whether using either the mouse-traverse or the ultrasonic positioning method, reduced the time to perform an accurate survey. In addition, the data handling, control, and management capabilities of the system made it possible to manipulate and report survey results in a more timely fashion. However, the performance of the system could be enhanced through modifications aimed at increasing user friendliness, system ruggedness, and transducer ranging capabilities.

CHAPTER 1
INTRODUCTION

For almost 50 years the United States has produced materials for nuclear weapons. With these activities, the generation of radioactive wastes has frequently contaminated sites (DOE, 1991; ORISE, 1993). The U.S. Department of Energy (DOE) has been given the challenge of identifying, managing, and cleaning-up these contaminated locations. This responsibility has resulted in the formation of a 5-year strategic plan: The Environmental Restoration and Waste Management Five Year Plan. Through this effort, DOE's mission is to eliminate potential radiological hazards to the public and the environment by returning these locations, through remediation efforts, to areas with acceptable levels of radioactivity (DOE, 1992). In addition, on recommendations from the State and Tribal Government Working Group, DOE committed to a 30-year goal for the clean-up of all present inventories of inactive sites (EPA, 1993). This long-term strategy is focused on eliminating or reducing potential risks to workers, the public, and the environment. To meet this objective, DOE plans to develop new technologies for containing, isolating, removing, and detoxifying on-site and off-site contamination.

The Formerly Utilized Sites Remedial Action Program (FUSRAP) has been funded by DOE for clean-up of locations that have existing radioactivity as a result of operations conducted by the Manhattan Engineer District (MED). The most common radionuclides

found on these sites are uranium-238, thorium-232, and their daughters (Hickey et al., 1988). Remedial measures at these sites quite frequently are concentrated indoors in vacated buildings. The four major tasks of FUSRAP are to designate, characterize, remediate, and verify the radioactive nature of a site and, with each of these tasks, there is an associated survey requirement.

In addition to remediating the radiological hazardous confines and sites directly associated with weapons development, DOE has the added responsibility of controlling, and subsequently, eliminating the potential radiation health hazard posed by the uranium mill tailings located at active and inactive uranium mills (Federal Register, 1983). It is estimated that approximately 12,000 surveys will be performed in close proximity to the 24 inactive mill sites (Little et al., 1988). At these mill sites, as well as at the previously discussed indoor facilities and outdoor waste sites, it is essential to perform radiological surveys in order to properly characterize and manage the release of potentially hazardous radiation from the uranium and plutonium decay chains. Other possible sites where radiological characterizations and assessments are required include gaseous diffusion and enrichment facilities, medical laboratories, private enterprises, etc. Thus, a means of optimizing the efficiency and effectiveness of such radiological monitoring and surveying is an imperative.

Current contaminated locations are found either in indoor development/storage facilities or at outdoor geological sites. It is approximated that 80% of past remediation efforts have been aimed at outdoor contaminated sites while only 20% of the efforts have been directed at indoor contaminated facilities. A current breakdown of the radioactive

waste sites designated for clean-up includes 15,000 Department of Defense sites, 9000 DOE sites, 422 Department of Interior sites, 96 Department of Agriculture sites, and one location managed by the NOAA (EPA, 1993). For all of these identified locations, an essential component of the decontamination and decommissioning effort, whether inside a building or outside on a controlled plot of ground, is the radiological survey (DOE, 1992; Berger, 1992; ORISE, 1993).

The objective of the radiological survey is to determine if a contamination is present, or, if a source is known to be present, to identify and monitor the levels of radiation in the area and compare the results with regulatory criteria (NRC, 1982; NRC, 1974; DOE, 1991; DOE, 1992). However, radiological surveys are a time consuming component of the total decommissioning process. Manual methods of performing surveys involve tedious and somewhat primitive recording methods. They require substantial man-hours tied up in survey technicians and, in addition, are not conducive to real-time data analysis and evaluation.

Various means of portably detecting and measuring levels of gamma, alpha, and beta radiation have been well tested and documented. A means of enhancing the radiological survey by simultaneously and portably collecting, storing, and analyzing both positional and exposure data, while still in the field, would be much more efficient than current survey techniques. Methods of automating the survey process at outdoor sites by using computers and ultrasonics have been proposed and field tested (Berven et al., 1991; Chemrad, 1992; Policastro, 1992; Wendling and Wade, 1994). But, as of this date, a totally integrated technique with the necessary accuracy indoors has not been tested.

The purpose of this research is to introduce an automated radiological survey methodology developed for performing site remediation and decommissioning. This integrated system makes it possible to efficiently and effectively monitor, collect, and analyze data from indoor contaminated sites in real-time. Thus, a more intelligent site assessment and consequential remediation effort can be made. In addition, the system provides a viable technique for performing the confirmatory surveys after the necessary decontamination has been completed. This method of automating and making portable the radiological survey process could provide DOE with a viable means for mastering the indoor decommissioning component of its 30-year compliance and clean-up goal.

CHAPTER 2
LITERATURE REVIEW

The Decommissioning Process

Facilities that use any radioactive material as a part of their activity will eventually conclude their operations. It is essential that, upon conclusion of these activities, special precautions will be taken to ensure that the environment and its future occupants are not subjected to unacceptable risks associated with residual radioactivity (Berger, 1992). In the United States, the U.S. Nuclear Regulatory Commission (NRC) has the licensing and regulatory responsibilities for many of these operations. The NRC has developed a series of requirements that must be met in order for the licensee to successfully terminate its license. These requirements are satisfied by following a process known as decommissioning.

Decommissioning is an interactive process between the NRC and the licensee that leads to the termination of a facility license and to the consequential release of the site for unrestricted use. Upon cessation of operations involving radioactive materials, it is the responsibility of the licensee to remove residual activity "as low as reasonably achievable" (ALARA) before the license is terminated. The following is a list of the other responsibilities of the licensee, per Title 10 of the Code of Federal Regulations (10 CFR), before termination is possible.

1. Termination of the use of licensed material.
2. Properly disposing of removed radioactive materials.
3. Submission of report form NRC-314.
4. Conducting a radiological survey of possible affected areas.
5. Submission of the final survey report to the NRC.

Release Criteria

The levels and limits established by the NRC and other responsible federal agencies (i.e., DOE, EPA) that have been identified as being environmentally acceptable are referred to as release criteria (NRC, 1974; NRC, 1987; Berger, 1992). Release criteria include guideline values for specific radionuclides as well as for specific conditions. The release criteria are typically given in units of direct radiation levels (e.g., mrad/h), surface activity levels (e.g., dpm/100 cm^2), or concentration (e.g., pCi/g). The release criteriasare given as the level found above background. The release criteria currently in use by the NRC are in the Regulatory Guide 1.86 (See Appendix A) and in Regulatory Guide 8.24.

The ultimate goal of the decommissioning process is to assure that the future uses of any licensed location, whether indoors or outdoors, will not result in individuals beings exposed to unacceptable levels of any type of ionizing radiation. The NRC has set general guidelines for surface activity, soil activity, and exposure rate (ORNL 1981; Berger, 1992).

Surface activity

Small areas of residual activity exceeding the guideline value (elevated area) may

be acceptable to the NRC. The criterion for acceptance is that the elevated area activity levels are less than three times the guideline values when averaged over a surface region of 100 cm^2. An additional constraint is that the level within a 1 m^2 area containing this elevated area is within the guideline value.

Soil activity

For soil activity, elevated levels are acceptable as long as they do not exceed the guideline value by greater than a factor of $(100/A)^{1/2}$, where A is the area of elevated levels in square meters. An additional constraint is that the level at any location does not exceed three times the guideline value (values should be averaged over 100 m^2 area).

Exposure rate

The exposure rate cannot exceed the background level by greater than the exposure rate limit. The reading is detected at 1 meter from the surface by an approved detector and instrument. In occupiable buildings, the measurement is taken at 1 m from the floors and walls and may be averaged over the floor and wall areas (not to exceed 10 square meters).

If the levels of residual activity are found to be below the established release criteria, and thus, inside the described criteria constraints as well, then the site is considered to be released with no further need for radiological controls. In essence, the site is identified as one that is acceptable for unrestricted use by the public or private entities. However, if a location has residual activity at levels above the criteria, it is considered contaminated.

Remediation

Usually, if a site has areas where residual activities exceed the guideline values, it can be adequately reduced to acceptable levels for unrestricted release. The process that brings the levels down below the threshold values is called remediation or decommissioning. Dependent upon the criterion radionuclide or radionuclides, there are various methods of remediating a site that have been deemed unacceptable. For example, low-level surface alpha emitters can be removed by such a simple procedure as applying "suds-and-water" with subsequent and adequate disposal of removing media. On the other hand, some sites, with extremely high levels of radioactive materials, cannot be practically remediated at all. Thus, alternative methods such as dry ice blasting, strip-painting, or long-term containment can be used.

The Radiological Survey

The radiological survey is considered one of the most time consuming and costly endeavors associated with the total decommissioning process. The ultimate purpose of the survey is to provide the minimum (95%) confidence that the release criteria guidelines, detailed in the preceding section, are met. There are several different types of surveys associated with the total decommissioning effort and each of these distinct types serve a unique purpose. In addition, each of these types of surveys provides its own measurement and technique challenges (Mann, 1994; Hickey et al., 1988). The main types of radiological surveys, with some variance between different groups as to what to call each

survey category, are the background survey, the scoping survey, the characterization survey, the remediation survey, the final status survey, and the confirmatory survey (DOE, 1992; Berger, 1992).

Background Survey

The background survey is essential to the total decommissioning process because the release criterion is in all cases presented as a level above the background radiation level. This survey requires the measurement of direct levels of radiation as well as the concentrations of potential radionuclides in the building construction materials, location soils, and area groundwater. In most cases, the main background radiation measurement will be the exposure rates from gamma emitters. These exposure levels can be easily and accurately checked by field survey instruments.

The background survey should have been performed prior to the initiation of licensed operations to provide a baseline. However, the existence of a previously conducted background survey is not always a reality, and, in such cases where a background survey was not carried out, a background survey should be performed prior to performing any other survey or remedial activities.

Background measurements should be made within the vicinity of the site. For the interior background samplings, a good choice would be in similar, on-site buildings where no licensed activities have been performed. It is imperative to sample inside a compatible building to obtain accurate background levels for indoor surveys rather than to rely on outdoor background readings. This is because many of the building materials contain

naturally occurring radioactive materials. In addition, the buildings tend to have a shielding effect that could also affect the readings.

Because the background level will be subtracted directly from the total residual activity levels, the detection sensitivity and accuracy of the instrument used to determine the background levels should be at least comparable to that of the instrument used to obtain the data for other surveys. The best way to provide this situation is to use the same instrument for all of the surveys performed. Another major concern is the number of background sampling locations and direct measurements that are required to provide the necessary level of confidence. As with all sampling schemes, the more samples taken, the more costly the process is in time and man-hours. However, it is essential to provide enough background measurements to have the confidence that the background rate used is close to the true rate. Experience has indicated that the variance from the average value for 6-10 measurements will not exceed 40-60% of the average at 95% confidence (Berger, 1992).

Scoping Survey

The scoping survey is performed early in the decommissioning process. The primary objectives of this type of survey are threefold (DOE, 1992):

1. To determine if residual radioactive materials are present or not.
2. To determine if the levels found exceed guidelines or not.
3. To determine if the data obtained are sufficient to estimate the possible health risks or not.

Scoping surveys are usually conducted after a preliminary site visit is made by the concerned parties. The scoping survey consists of the necessary measurements to determine if there is a substantial site contamination. Typically, this survey involves taking limited direct exposure rate and surface activity readings from site locations where there would be the greatest chance of finding elevated levels of contamination. In addition, levels are taken at locations where there is no activity involving radioactive materials have occurred as well as at locations adjacent to suspected contaminated areas. The data are compared and evaluated and a judgement is made whether to classify it as an "affected" or "unaffected" area.

The scoping survey is a means of planning further efforts that might be necessary to complete the decommissioning process (i.e., characterization survey details, man-hours required, timing, instrumentation needed, etc.). This type of survey is not as comprehensive nor as sensitive as the characterization, remediation, or final status survey. However, the scoping survey is an essential component of the total decommissioning process because it provides data for further planning. It should be noted that readings obtained from the scoping survey can be used as data points for subsequent surveys and, for sites where the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is applicable, sufficient data should be collected to complete the Preliminary Assessment/Site Investigation (PA/SI) portion of the total process (EPA, 1989a).

Characterization Survey

The characterization survey is performed after the scoping survey has identified affected areas that will need decontamination or remediation efforts. This type of survey is performed to more accurately and precisely identify the specific locations of residual activity as well as the relative magnitudes of contamination.

The characterization survey is a detailed process that involves such components as spatial gridding and the collection of both systematic and biased samples (DOE, 1992; EPA, 1982; Policastro, 1992). Analysis of the data obtained from the characterization survey is useful for determining ALARA assessments, time and man-hour cost estimates, and recommendations for remedial action. The characterization survey is the most comprehensive type of radiological survey and provides concerned parties with the most data for decision making. When CERCLA is applicable, enough points must be sampled to fulfill the requirements of the Remedial Investigation/Feasibility Study (EPA, 1976).

The main purpose of the characterization survey is to provide the necessary information to establish the requirements for remedial action. Efforts are concentrated in the characterization survey where it is suspected (or verified from the scoping survey) that radiation levels exceed release criteria and guidelines. However, sampling locations should be observed systematically as well as biased in order to make individual comparisons and site profile comparisons. After the site has been completely characterized for type of radionuclide, magnitude of radioactivity, and location of elevated radioactivity levels, site remediation efforts are begun.

Remediation Survey

This is the type of survey performed during decontamination. Another name for the remediation survey is the remedial action survey. This type of radiological survey guides the cleanup in a real-time mode (Berger, 1992). As an added purpose, it is designed also to protect the remediation workers against exposure to radioactivity during the decontamination activities.

The remediation survey provides the affected parties with an indication of whether or not the contaminants are being removed and if the decontamination effort is effective in bringing down the radioactivity levels below the release criteria guidelines. Such a survey is usually not designed to provide a thorough and accurate compilation of data to be utilized as final status information (DOE, 1992). A simple radiological parameter is usually provided and an elaborate system of positioning or gridding is not normally used.

Final Status Survey

The final status survey is performed to give detailed information on the extent of the removal of the original contamination. Since this survey provides data on the final condition of the site, many accurately sampled points are necessary for data quality assurance, thus the measurement challenges are paramount (Mann, 1994; Berven et al., 1991; Hickey et al., 1988). This type of survey is known by other names such as termination survey, post remedial-action, and final survey.

The final status survey provides the survey team with a comprehensive radiological

assessment following decontamination. It is this survey that provides the necessary data to demonstrate that all parameters (i.e., total surface activity, removal surface activity, positional data, exposure rate, etc.) satisfy the survey plan release criteria (Berger, 1992). Accurate spatial determinations are critical to the success of this evaluation. Results are detailed in report form and are used by the licensee to terminate its license. As mentioned previously, data from other types of surveys (e.g., scoping, characterization) can be utilized as part of the final status survey. The latter surveys essentially provide a record of the radiological characterization of a new site (DOE, 1992).

Confirmatory Survey

This type of survey is performed by the NRC after it receives the licensee's final status survey. It is like an "audit" survey to confirm or verify the findings detailed in the termination survey report supplied to the NRC by the licensee. The majority of the work involved with this type of survey is not field sampling but rather a review and assessment of the documentation supplied to NRC by the licensee.

The objective of the confirmatory survey is to verify that all of the characterization, remediation, and post-remedial activities were performed adequately and provided for a "radiologically clean" site, acceptable to the criteria for unrestricted use by the public or other private concerns (DOE, 1992). Measurements are made only over limited areas (usually those identified earlier as "affected") and are used to verify the results of other survey findings. Accurate positioning data, therefore, are essential also to the confirmatory surveying process.

A confirmatory survey involves spot-checking of from 1 to 10% of the total surface area (Berger, 1992). However, if problematic conditions exist, the survey can be extended to encompass a much greater area. The NRC uses the results of this audit to base and support its decision on whether or not to terminate a license.

Survey Work Plan

The survey work plan should be designed to explain the details of the particular type of survey needed. It is important to include the following parameters (Berger, 1992).

1. The types, numbers, and physical locations of the sample measurements.
2. The methodology and instrumentation used for sampling and analysis.
3. The evaluation and assessment techniques employed.
4. The quality control/quality assurance procedures utilized.

The approach followed should be one that will optimize quality and cost-effectiveness. Special attention must be taken not to produce redundancy in data gathering. In addition, the plan should help facilitate party interfaces and interactions.

Before the work plan can be detailed, there are several factors that must be addressed in the pre-planning process. Initially, the radiological status of the site must be assessed. The site license and documentation (e.g., maps, process flow charts, conditions, etc.) should be reviewed and radioactive materials used at the site need to be identified. An evaluation of the potential and the likely location of these radionuclides should be considered. Such factors as historically-observed contamination, decay time allowed, and daughter ingrowth should be addressed by the decommissioning team.

After this initial information gathering stage, a scoping survey needs to be performed with the appropriate instruments. In addition, the guideline values for the site should be established. Usually, for a single radioactive material or a combination of radionuclides with the same guideline values, the release criteria are selected from the NRC tables. However, if in the pre-planning phase, multiple radioactive materials are identified, site-specific guidelines should be developed..

The scoping survey should provide the affected parties with information that will be utilized to initiate the next steps. If the levels exceed the release criteria or site-specific guidelines, it will be necessary for the survey team to perform characterization and remediation surveys. If however, it can be demonstrated that there is no residual contamination, then the NRC may determine that no further actions by the licensee are necessary to terminate the license.

The survey work plan should not be considered to be rigid in design (Policastro, 1992; ORISE, 1993; DOE, 1992; Berger, 1992; Mann, 1994). Instead, as conditions dictate, the plan can be modified to accommodate new information or changes that occur. Thus, the plan must be flexible and those who have the authority to make changes to the plan should be identified.

The survey plan is site-specific. Special consideration should be given to sampling schemes, equipment and small item sampling, and the actual physical layout of the area to be surveyed. Although there are theoretically an infinite number of locations that could be sampled, achievement of this is not practically possible. Therefore, attention must be given to gather data from a sufficient representative number of site locations.

The physical characteristics of the site will have a significant impact on the time and cost requirements of the survey. For building interiors, the construction features will determine the accessibility of the various surfaces of interest (i.e., walls, floors, ceilings, etc.). If porous materials have been used, contamination could have penetrated to sub-surface layers as well as become fixed in the matrix of the material. In addition, for painted surfaces, contamination could be fixed under the paint layer. Surface conditions can also affect the survey process and such techniques as coring or drilling to reach covered contamination may be required.

Specifically, for indoor surveys, the survey work plan needs to identify the various surfaces of interest. Normally, the four walls, floor, and ceiling are the survey areas that must be covered. In addition, one would expect to find contaminated indoor surfaces such as hot cells, fume hoods, piping, and ducting (DOE, 1992). A survey reference system, based on the contamination potential for the area, should be developed. Schematic drawings should be designed to provide spatial information that could help to facilitate the survey process. If possible, scale drawings of the survey areas should be obtained as a supplement. In essence, the physical characteristics of the survey site will have a heavy impact on the complexities associated with this process. Thus, factors such as the size, number, type, condition, and area of the building(s) are critical in designing a quality survey work plan.

During the development of the survey work plan, considerations should be made regarding quality assurance, health and safety, instrumentation, sampling locations, data management, and reference gridding. Appropriate programs in quality assurance, health

and safety, and data management, that has been developed and administered by responsible personnel, will help to effectively and efficiently facilitate the progress of the survey. The scope and type of specific programs utilized in these areas will be determined by the site-specific conditions.

Instrumentation

Radiological instrumentation primarily consists of two components, a radiation-specific detector and the necessary electronic equipment to power the detector and measure the response. Several of the current detectors and instrumentation used to sample and measure radiation levels are listed in Table 1. The choice of detector or instrument is dependent on many factors including survey type, radiation type, and physical surroundings.

Other general requirements include portability, ruggedness, user-friendliness, ease of maintenance, ease of decontamination, reliability, and accuracy. The survey instrument must be calibrated quite frequently for the specific radiation type (Cember, 1989). Some of the critical characteristics of the survey instrument include its sensitivity, radiation-specific response, response time, and energy dependence.

The measurement of direct gamma radiation is usually performed using a portable ratemeter coupled to a sodium iodide detector (Schleien, 1992; Hickey et al., 1988). It is very important to keep in mind that the response of a NaI detector is dependent on the gamma ray energy spectrum. Thus, site-specific calibrations are necessary with portable instruments. Exposure measurements are performed at one meter above the surface and

TABLE 1
RADIOLOGICAL SURVEY INSTRUMENTS AND DETECTORS

Radiation Type	**Detector Type**	**Rate Meter/ Scaler**	**Sensitivity (dpm/100 cm2)**	**Remarks**
Alpha	Ludlum, 43-5 Eberline, AC3-8 Bicron, A-50	Eberline, PRS-1 Ludlum 2350 Bicron Analyst	<50	Surface contamination surveys only.
Beta / Gamma	Eberline, HP260 Bicron, PGM	Ludlum 2220 Ludlum 2350 Eberline, PRM-6 Bicron, Analyst	<400	Sensitive to microwave fields.
Alpha / Beta	Ludlum, 43-89 Eberline, SAC-4 Ludlum, 239-1	Ludlum, 2350 Ludlum, 2220	<20 Alpha <100 Beta	Alpha/beta discrimination requires special rate meter.
Gamma	Bicron, Fidler Ludlum, 44-10 Eberline, PG-2	Bicron, Analyst Ludlum, 2350 Eberline, ESP-2	Dependent Upon Background	Must perform on site calibration.

the count rate is converted to microR/hr using the calibration curve. However, with some of the newer instruments, calibration routines can be performed prior to the survey. These routines typically involve counting of radiation from two known sources and the determination of a calibration constant (Ludlum, 1992).

For surface alpha surveys, zinc sulfide scintillation probes or large gas-flow proportional counters coupled with digital ratemeters/scalers are used (Policastro, 1992; Hickey, 1988). However, gas proportional counters and silicon surface barrier detectors can also be used (Wang et al., 1975; Berger, 1992; Shleien, 1992).

For most of the beta surveys conducted, a thin end-window Geiger-Mueller tube is used in conjunction with a digital ratemeter/scaler. Also, field beta emission surveys are conducted with large-area gas-flow proportional counters and plastic scintillators (Hickey et al., 1988). The gas-flow proportional detector can be used to measure very low energy beta emissions (ORISE, 1993).

Minimum Detectable Activity

The detection sensitivity of the instrument or particular measurement system is defined as the statistically determined quantity of radioactive material or radiation that can be measured or detected at the predetermined level of confidence. The detection sensitivity is a function of both the limitations and biases of the technique and instrumentation used in the process (Berger, 1992). Normally, the detection sensitivity is indicated as the level above which there is less than a 5% probability that the radioactivity will be reported when it is not there (Type I error) or not reported when it really does exist (Type II error) (EPA, 1980).

The lower limit of detection (LLD) and the minimum detectable activity (MDA) are two terms that refer to process and instrument detection sensitivity (Shleien, 1992; Berger, 1992; ORISE, 1993; EPA, 1980). The LLD is an estimated instrument detection

capability while the MDA is an estimate of the minimum activity level that can be measured by a specific instrument. For most radiological surveys, the emphasis is placed on determining the MDA of the process rather than the LLD of the particular instrument. Thus, a more thorough explanation of the MDA will be given.

The basic mathematical relationship for determining the MDA is given below:

$$MDA = k(2.71 + 4.65S_b)$$

where	MDA	=	minimum detectable activity level in dpm/100cm^2
	k	=	a proportionality constant relating the detector response (in counts) to the activity concentration
	S_b	=	the background count standard deviation

For an integrated surface activity measurement over a predetermined time, the minimum detectable activity can be estimated by the following relationship (ORNL, 1993, ORISE, 1992; Berger, 1992).

$$MDA = \frac{2.71 + 4.65\sqrt{(B_r t)}}{t\,E\,(A/100)}$$

where	MDA	=	activity level in disintregrations/minute/100 cm^2
	B_r	=	background rate in counts/minute
	t	=	counting time in minutes
	E	=	detector efficiency in counts/disintegration
	A	=	active probe area in cm^2

In addition, the ratemeter's MDA for site surface activity measurements can be estimated by doubling the meter's time constant and using this as the counting time (Knoll, 1979;

Berger, 1992). The mathematical relationship is as follows.

$$MDA = 4.65 \frac{\sqrt{\frac{B_r}{2t_c}}}{\frac{EA}{100}}$$

where

	MDA	=	activity level in disintegrations/minute/100 cm^2
	B_r	=	background rate in counts/minute
	t_c	=	meter time constant in minutes
	E	=	detector efficiency in counts per disintegration
	A	=	active probe area in cm^2

<u>Gridding</u>

In order to spatially identify the various radiological measurements taken in a manual survey, a reference grid is developed. These grids are created for reference purposes and do not necessarily provide the spacing for the sampling scheme. However, the grids can provide the survey team with a means of facilitating the systematic selection of measurement locations as well as a method of determining average area activity levels (Berger, 1992).

A grid is a system of intersecting, parallel lines that are referenced to a coordinate origin (i.e., 0,0,0). The survey grid lines are typically arranged in a perpendicular fashion and divide or stratify the survey area into squares of equal area. For indoor surveys of structures, it is recommended that the basic grid intervals be 1 meter (Hickey et al., 1988;

Berger, 1994; ORNL, 1990; ORISE, 1992). However, larger spacings can be used for bigger rooms and for facilities with radionuclides that have much higher values than the guideline. Normally, as a minimum, the walls are also gridded from the floor up to 2 meters in height. If spot checks of wall surfaces higher than 2 meters reveal contamination, then additional gridding may be required. In addition, other surfaces suspected of contamination may be gridded.

A typical technique for grid identification is to numerically reference either the vertical or horizontal axis and to alphabetically label the other as is. Figure 1, Figure 2, and Figure 3 are diagrams of building interior grid schemes. Figure 1 shows an example of the sampling pattern for systematic manual grid surveys. Figure 2 is a three dimensional representation of an indoor grid system while Figure 3 shows another possible grid system for an example remediation project.

Frequently the survey technicians will use proven "short-cuts" to grid a room, thus saving some of the time required to perform the complete survey. For example, if the room is tiled, the technicians can count the number of floor tiles to provide approximate spatial coordinates. However, this methodology is not endorsed by the usual site standard operating procedures, and therefore, should not be considered as a recommended gridding technique for indoor radiological surveys. In addition, the survey technicians will determine the background rate at only a few locations and not necessarily at locations described by the standard operating procedures.

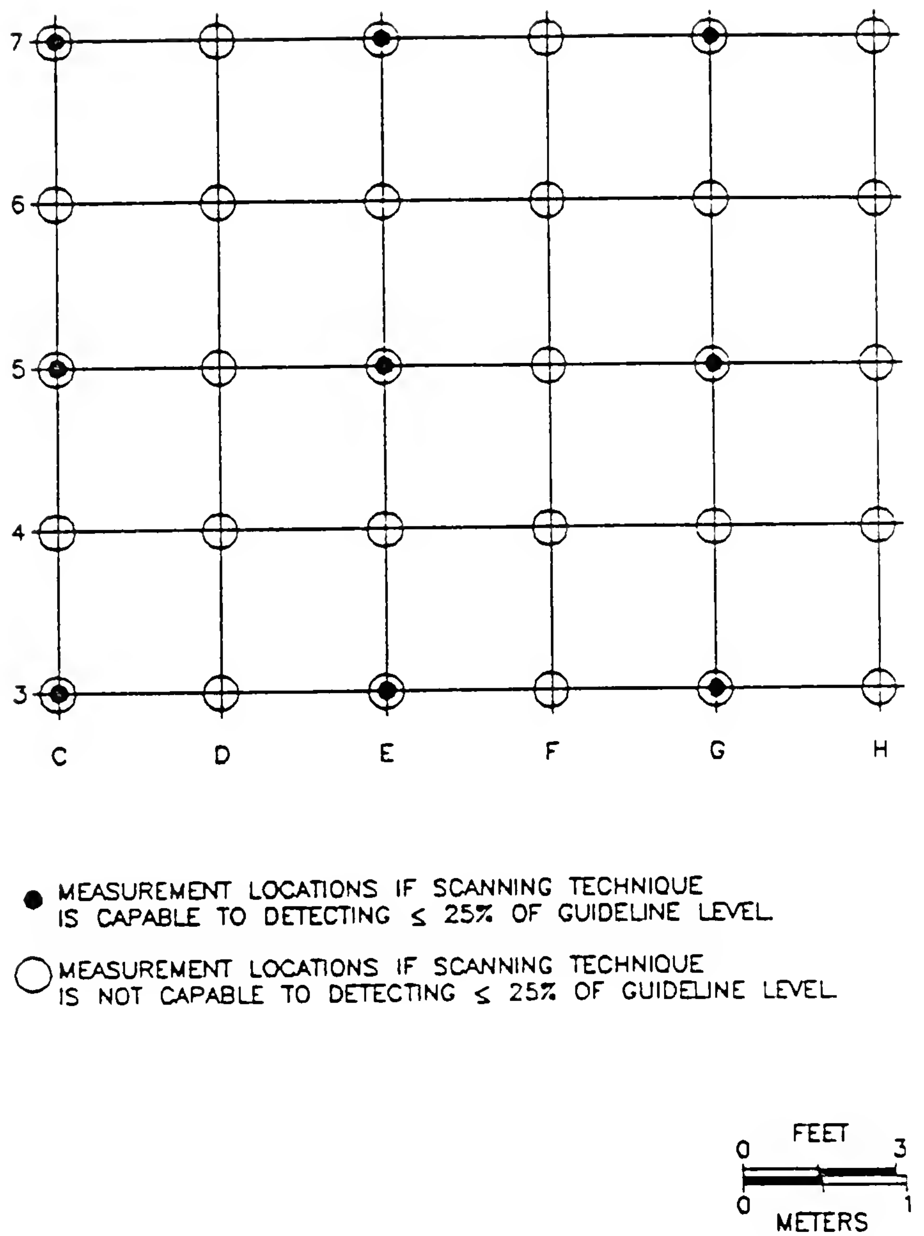


Figure 1. Sampling Pattern for Systematic Grid Survey (from Berger, 1992).

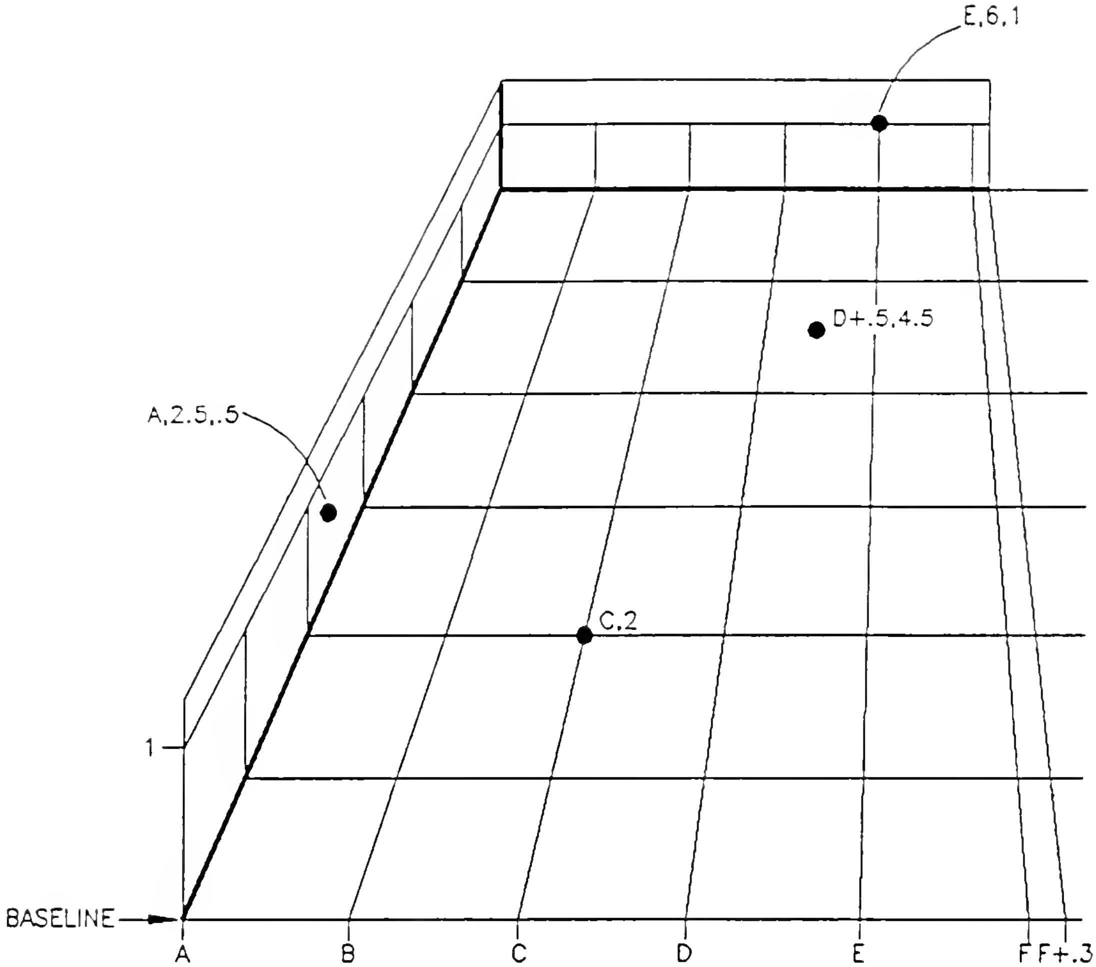
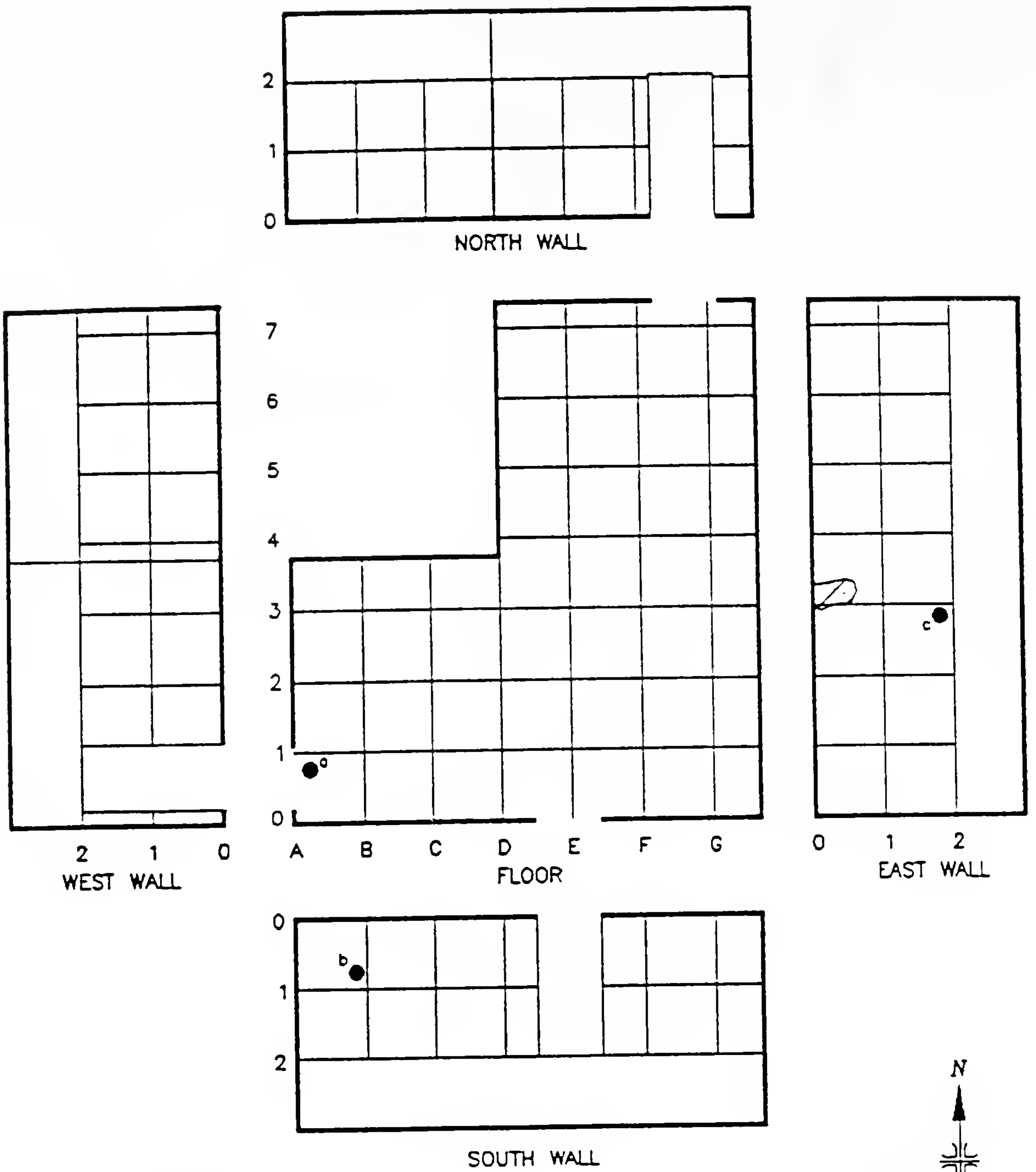


Figure 2. A 3-D indoor grid system (from ORISE, 1993).



EXAMPLE OF
GRID POINT DESIGNATION

POINT	GRID DESIGNATION
a	A+0.2, 0.8
b	A+0.8, 0, 0.8
c	G+0.6, 2.9, 1.9

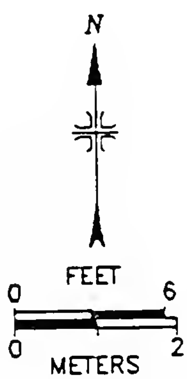


Figure 3. Example grid system (from Berger, 1992).

The basic procedures required in developing a reference grid system begin by obtaining a calibrated measuring tape. Next, a grid baseline is generally selected to be the longest dimension of the room. Usually, for indoor surveys, a specific corner is referenced as 0,0,0 or A,0 or something comparable. ORISE recommends that gridding should be done in the metric system (i.e., 1 meter intervals) and spacing should be determined based on potential contamination. The main items of equipment needed for the gridding process are a calibrated measuring tape, grid markers, masking tape, markers, paint, and chalk (ORISE, 1993; DOE, 1986; DOE, 1987).

The grid blocks of 1 meter by 1 meter are identified on the floor and lower walls using either a chalk line or other markers (e.g., paint, marking pencils, etc..). Usually, A,0 or the starting point is the southwest corner of the room. Grid line intersections are marked and identified by the alpha-numeric system mentioned previously. Any location meant for sampling is spatially located by measuring the distance from the sampling point to the grid marker. Small rooms (i.e., less than 10 m^2) do not require gridding. Upper walls and ceilings are usually not gridded (ORISE, 1993). The detailed recommended standard operating procedures for radiological survey gridding are given in Appendix B.

Manual Standard Operating Procedures for Radiological Survey Measurement

A detailed set of procedures is given in Environmental Survey & Site Assessment Program (ESSAP) Survey Procedures Manual for the various types of radiological survey measuring at indoor locations. However, this section briefly describes the more important characteristics of performing indoor surveys for gamma, alpha, and beta radiation.

A scoping survey is performed to determine the level of gross activity present at the site. As mentioned earlier, this type of survey is done before the more detailed characterization survey is accomplished. Scanning is done for all potential radionuclides and action levels are based on the site-specific activity guidelines (ORISE, 1993).

For gamma radiation emission measurement, a recently calibrated NaI gamma scintillation detector, coupled with an electronically calibrated ratemeter/scaler, is recommended. Approved operational check-outs should be performed before the survey is begun. To scan the affected area, set the instrument to fast response and slowly (i.e., 1 meter per second) pass the detector over the surface area. The NaI detector is usually swung in front of the body in a pendulum manner while walking slowly forward (DOE, 1986; Mann, 1994; Berger, 1992; ORISE, 1993). Points are marked where the measured values exceed predefined "action levels".

For beta radiation emission measurement, a GM pancake type detector coupled with an audible ratemeter/scaler is recommended. As with the gamma survey, an approved operational check-out is performed before the actual survey is begun. To scan the location for beta radiation, the detector is passed slowly (e.g., at one detector width per second) over the surface as close as possible. The surveyor listens to the audible meter for increases in the rate and marks locations that exceed the site guidelines (ORISE, 1993, DOE, 1987).

For alpha radiation scanning, an alpha scintillation detector used in conjunction with a portable ratemeter is the recommended measurement system. Since alpha particles only penetrate a maximum distance in air of about 2 centimeters, an accurate surface scan

must be as close to the surface as possible. The detector is moved at about one detector width per second and increases in the audible output of the meter are recognized and located if above the action level guides (ORISE, 1993).

For more in-depth and detailed surveys (i.e., characterization survey, final status survey), measurements for gamma, beta, and alpha radiation are specified at a certain location over an appropriate counting period. Gamma measurements are taken at 1 meter from the surface and a background rate should be determined prior to the start of the survey. As for the scoping surveys, an operational check-out of the instrument and detector should be performed prior to beginning the survey. An appropriate measuring system includes a NaI scintillation detector and a digital ratemeter/scaler. One should observe the count rate displayed on the meter at the desired spatial position. Depending on the instrument output, a conversion from count rate to exposure rate may be required (DOE, 1986; DOE, 1987; ORISE, 1993).

Instrument calibrations should be traceable to the National Institute of Standards and Technology (NIST), and the user may choose to calibrate the instrument or have it performed by an outside vendor (ANSI, 1978; NCRP, 1985). It is recommended that field instruments like the Ludlum 2350 ratemeter/scaler or the Eberline PRS-1 be calibrated at least semi-annually and following any maintenance (Berger, 1992).

The SOPs for conducting characterization survey measurements for beta radiation require a detector comparable to a GM Pancake with the necessary interface to a digital ratemeter/scaler. An operational check-out is made prior to the start of the survey and a site background is determined. Depending on the site-specific guidelines, it is sometime

necessary to calculate the action level. The following relationship can be used:

$$Action\ Level\ (cpm) = C_s EGT + B$$

where	C_s	=	site criteria in dpm/100cm^2
	T	=	count time in minutes
	E	=	operating efficiency (counts/disintegration)
	G	=	geometry (detector area cm^2/100)
	B	=	background in counts per minute

A field count above this action level dictates a further investigation is necessary at this location. Thus, it can be termed an "affected" area. To proceed with the survey measurements, a counting rate of approximately 1 minute (based on the radionuclide) is established and values are logged by both location and magnitude. The measurement reading should be taken as close to the surface as possible. Finally, the beta measurement should be recorded as beta dpm/100 cm^2 by subtracting out the background to get net counts and applying factors for time, detector efficiency, and effective area (ORISE 1993; Berger 1992; DOE, 1986; DOE, 1987; Wang et al., 1975; Cember, 1989).

Alpha radiation measurement methodology is basically the same as for beta measurement. However, the type of detector needed is one comparable to a ZnS scintillator or a large gas-flow proportional counter to detect alpha particles accurately. The action level can be determined in the same manner as that for beta measurement. It is necessary to perform an operational check-out as well as a background survey prior to starting the actual alpha survey. The alpha survey detector must be placed on the surface of the area of concern to detect alpha levels. A count time of one minute is usually used

and a calculation of alpha dpm/100 cm^2 is found by subtracting the background rate to obtain net counts and by applying appropriate factors (i.e., time, detector efficiency, and effective area). The following mathematical relationship can be used to determine net surface alpha (DOE, 1987; ORISE, 1993; Wang et al., 1975):

$$\alpha\, dpm = \frac{N}{TEGF} 100\, cm^2$$

where	N	=	net counts
	T	=	count time in minutes
	E	=	operating efficiency (counts/disintegration)
	G	=	geometry (detector area cm^2/100)
	F	=	other modifying factors

For gamma, alpha, and beta surveys, the measurements should be performed per the quality control procedures outlined in the ESSAP Quality Assurance Manual prepared by ORISE or by QC procedures detailed in another DOE/NRC-approved publication. Statistically determined sampling schemes are imperative to the success of the whole survey process and should be examined.

Survey Measurements and Sampling Statistics

Since residual contamination is usually concentrated in a small portion of the site and is asymmetrical in nature, a well designed sampling scheme is imperative to a successful survey and subsequent site assessment. Much of the activity is often located in small isolated "hot-spots", thus, a thorough scan of all suspected and/or affected surfaces as well as adjacent locations should be performed.

For characterization and final status surveys, systematic measurements and sampling are performed in affected and adjacent areas. The usual technique is to obtain at least five data points for each 1 m^2 of building surface (ORISE, 1993). In addition, it is typical for a survey team to take readings at representative "hot-spot" sites in order to obtain data on the upper ranges of residual activity levels.

For indoor surveys, it is recommended that the floors and walls of affected areas receive 100% coverage during the final status and characterization surveys. Upper walls, ceilings, and overhead surfaces which are suspected of having activities of greater than 25% the guideline should also receive 100% survey coverage (Berger, 1992; DOE; 1992).

Radioactive decay is a random process and can be approximated by the Poisson distribution (Cember, 1989; Wang et al., 1975). In addition, each value reported during the survey sampling should be indicated with an assessment of its uncertainty (EPA, 1980). Thus, an explanation of the sampling scheme and supplementary sampling statistics is necessary.

Based on the Poisson distribution, the best approximation of the standard deviation for the number of counts is the square root of the counts:

$$s = \sqrt{c}$$

where s = standard deviation
c = number of counts

The standard deviation in a count rate over time would be:

$$s = \frac{\sqrt{c}}{t}$$

where	s	=	standard deviation
	c	=	number of counts
	t	=	time in seconds or minutes

It can be seen that the longer the sample is counted, the less the uncertainty in the measurement. However, the increased time associated with taking more counts does not bring added benefits of compatible incremental increased certainty. Usually, a certain level of confidence in the survey measurements is agreed upon and accepted (e.g., 95 %).

The number of counts due to background is a significant amount and should be accounted for in nuclear statistics (Cember, 1989; Berger, 1992; ORISE, 1993; Shleien; 1992; Wang et al., 1975). Since the background counts also have an associated uncertainty, the relationship is:

$$s = \sqrt{\frac{c}{t^2} + \frac{B}{t_b^2}}$$

where	B	=	the background counts
	t_b	=	the time period over which the background was determined

Typically, the uncertainty is given at the 95% confidence level. Thus, to represent

the sampled data at this confidence level, the reported value should be X +/- (1.96)(s). The number 1.96 represents the 95% confidence level while the standard deviation, s, represents the expected amount of statistical variability about the mean. This type of error is known as the counting error and represents only one of several types of error associated with the survey process. Other sources of uncertainty include counting time (usually, kept at 1 minute during the survey process), distance and area measurements, detector and instrument efficiencies, and chemical recovery factors (Berger, 1992). Repeated measurements (e.g., 6-10 samples) with determinations of the means and standard deviations of the data sets can help to provide an upper bound on the magnitude of systematic uncertainties (EPA, 1980).

All data for the final status and characterization surveys should be reported as a certain sampled activity with a calculated uncertainty level. In addition, the minimum detectable activity (MDA) should be given (Berger, 1992). As with all measurements, the number of significant figures reported is important. Instrument accuracy limitations should be reflected in the sampled values (EPA, 1980). Appendix E provides several of the NRC approved forms used by survey teams to report the final status survey results.

The data obtained during sampling must, of course, be compared to the site guidelines or release criteria. If the sampling results in removable activity levels >20% of the guideline, then remediation and resurvey are required (ORNL, 1993; Berger, 1992). For areas of elevated activity inside buildings, the limit is three times the guideline value, when averaged over an area of 100 cm^2. Also, average surface activity within the 1 m^2 area containing the hot-spot must be less than the guideline value. Location specific

maximums (averaged within 100 cm^2) are acceptable to three times the guideline, given that the average over 1 m^2 is within the criterion. For exposure rate levels, the maximum exposure rate may not exceed two times the criteria levels above the background rate. Average rates are determined for occupiable building locations over a surface area of 10 m^2 and compared to a guideline value. If average rates or maximum rates are found above the guideline value, the area should be remediated and resurveyed (Berger, 1992).

The average levels of surface activity and exposure rates for indoor sites should be calculated using measurements within that area (DOE, 1992; Ott, 1988):

$$Xbar = \frac{\sum_{i=1}^{n} x_i}{n}$$

where $Xbar$ = sample average
n = number of samples
X_i = specific i_{th} sample

The averages for each survey unit (i.e., group of contiguous grid regions) are determined and compared with the site-specific guidelines. In addition, a further evaluation is made to determine whether or not the average survey unit values provide a 95% confidence level that the true survey mean value is within guidelines. The following equation is recommended for this analysis (EPA, 1989b):

$$\mu = xbar + t\frac{s_x}{\sqrt{n}}$$

where t = 95% confidence level value from t-stat table
$xbar$ = calculated mean
s_x = standard deviation of the sample
n = number of individual data points

If the value for the population mean is within the guideline, then the area does not need to be further remediated or resurveyed. The 95% confidence criteria means that the probability is less than 5% that the true mean activity level is above the criteria value (Ott, 1988; Gilbert, 1987). Thus, according to the site-specific plan, the site is acceptably "clean".

If, however, the population mean for the site is greater than the NRC guideline value, there will possibly be a need for additional sampling. If the mean is greater than or equal to the guideline, then remediation is needed in the area. On the other hand, if the mean is less than the NRC guideline, a larger sampling might be needed to demonstrate compliance. The following relationship can be used to determine the number of sampling points that are required to demonstrate compliance to the NRC guidelines at the given level of confidence (Gilbert, 1987; NCRP, 1985; Berger, 1992):

$$n = \left(\frac{s_x}{C_G - xbar} \right)^2 (Z_1 + Z_2)^2$$

where n = number of data points required
C_G = guideline value
$xbar$ = mean
s_x = sample standard deviation
Z_1 = false positive probability
Z_2 = false negative probability

All books on statistics provide the standard normal variables used in the above equation.

The determination of the number of background points to take on-site is also of importance if the average background rate is significant, relative to the guideline. The background rate is deemed significant if it is > 10% the NRC guideline values. However, if it is < 10% the value, then 6-10 samples are adequate for the radiological survey procedure (Berger, 1992; ORISE, 1993; DOE, 1992). More sampling points are needed if the background exceeds this 10% criterion, and the average of these points should accurately assess the true background average to within +/- 20% at the 95% confidence level (Berger, 1992). The following relationship can be used to calculate the number of background samplings that are necessary in cases where the background rate is significant:

$$n_B = \left(\frac{t_{stat} s_x}{0.2(xbar)} \right)^2$$

where	n_B	=	number of background measurements required
	x-bar	=	mean of initial background measurements
	s_x	=	standard deviation of background measurements
	t_{stat}	=	t-statistic (at 95% confidence and df=n-1)

Most statistical texts provide a list of t-values at the 95% confidence level.

A site inventory is calculated and reported as a total, site-specific level of residual activity. This reported quantity provides a comparison measure to established limits as well as a means for estimating potential future impacts on public health and safety and on the environment. It can be calculated by multiplying the surface area of a survey unit by the mean level of activity per unit and then summing up all the survey unit activities

(ORISE, 1992; NRC, 1982; ORISE; 1993; EPA, 1983; Berger, 1992). In essence, it is the integrated activity level of all radionuclides at the particular site.

Positioning

Because radiological surveys require a sufficient number of sampling points to characterize the radiation present as well as to verify conditions (DOE, 1992), employing a method of automated positioning could reduce the time and costs required to complete the site-specific survey. Thus, by eliminating the manual gridding procedure, the total decommissioning process could be completed in a more timely fashion.

Spatial positioning or range finding refers to the process of determining the distance between a reference source and a target (Rueger, 1989). The instruments used to measure this distance are referred to as either positioning systems or range finders. Some of the known spatial positioning techniques include the global or positioning system (GPS), inertial positioning, ultrasonic ranging, laser positioning, and mouse-traverse positioning (Wolf and Brinker, 1994; Rueger, 1989; Berven et al., 1991; Polaroid, 1994; Blitz, 1971; Brinker and Minnick, 1987; Broch, 1973, Lafreniere, 1994). The following provides an examination of these ranging techniques and their applicability to the survey process.

The Global Positioning System (GPS)

Global positioning involves the use of satellites and originally emerged from military research and subsequent applications (Wolf and Brinker, 1994; Brinker and

Minnick, 1987). The GPS can be operated at either day or night, rain or shine, and does not require cleared lines of sight between stations. The system does not rely on measured angles and distances for determining points. Instead, locations are determined by computer-based instrumentation that calculates spatial information through the use of algorithms and satellite frequency transmission, reception, and time differences. Thus, these attributes make it possible for the GPS to handle accurately and efficiently most outdoor positioning requirements (Rueger, 1989; Wolf and Brinker, 1994; Cooper, 1987; Wendling and Wade, 1994; Puttre, 1992; Stallones et al., 1992).

Satellite surveying systems grew out of the space program and Polaris submarine programs during the 1960's. The early satellite receivers were bulky and expensive, took a great deal of time to perform, and had only moderate accuracy (on the order of 1 or 2 meters). However, today PCMCIA GPS models are readily available that fit right into a Type II slot on a notebook computer and cost less than $900 (Trimble Navigation, 1994).

History

Development began in 1958 on the first generation satellite system and the precursor to the GPS. This system operated on the Doppler principle and utilized Navy's TRANSIT navigation satellites. The first satellite survey was accomplished in 1967 (Wolf and Brinker, 1994).

This process involved the use of ground station receivers and polar orbiting satellites at altitudes of 1075 km. Radio signal frequencies were transmitted by the satellites and the ground receivers measured the associated changes as the satellite moved along its known path. A Doppler shift resulted from the differences in the frequencies

detected, and the position of the ground station can be obtained by intersecting hyperboloids of revolution. In essence, the Doppler receiver measures the distance differences between the internal reference frequency and the transmitted frequency (Rueger, 1989; Haug, 1980; Brinker and Minnick, 1987; Wolf and Brinker, 1994). The accuracy of Doppler positioning depended on the length of time the satellite signals were recorded and on the type of subsequent processing performed (Rueger, 1989). For example, if 30-40 passes are observed with times of 2-8 days, positioning errors are around 1 meter (Wolf and Brinker, 1994). Figure 4 illustrates the Doppler effect in satellite positioning.

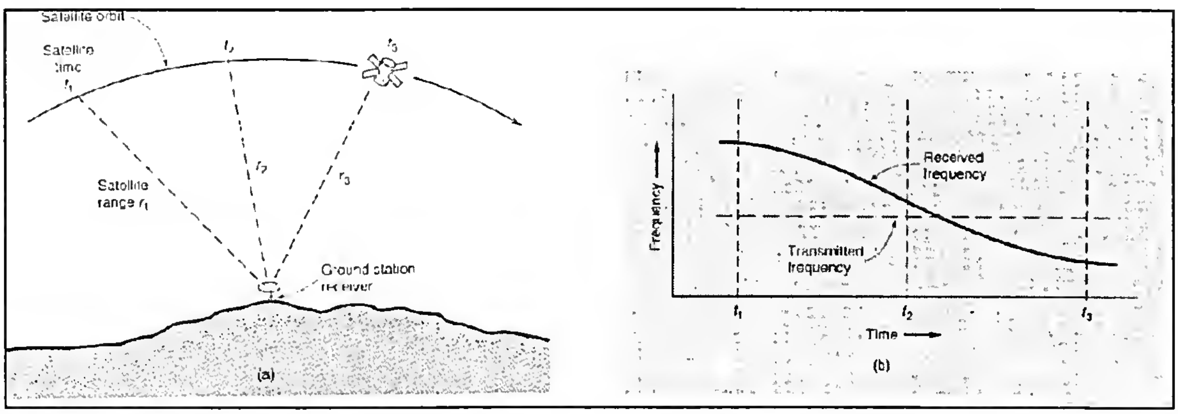


Figure 4. Doppler effect in satellite positioning (from Wolf and Brinker, 1994).

Doppler effect positioning has now been phased out by the development of the higher accuracy global positioning system (GPS). In 1978 the first satellite of the GPS system, NAVSTAR, was launched. The fully operational GPS consists of a constellation of 24 satellites.

Background and theory of operation

The GPS works on the same premise as the Doppler effect system with the observations of signals transmitted from satellites whose traveled paths and positions are precisely known (Goad, 1989; Heuverman et al., 1983; Gerdan, 1992). The receivers pick up transmissions at ground locations, and, as with Doppler method, accurate ranges or distances from the satellites to the receivers are determined from the timing and signal information. However, the signals and the subsequent distance determination methodologies are quite different from those of the Doppler type satellites.

The GPS is first military and then second civilian in purpose (Brinker and Minnick, 1987). Thus, the communication process is "one-way" (from satellite to receiver). The satellites are in near-circular orbits of 20,200 km and from four to six of the satellites are visible at any one time anywhere on earth (Wolf and Brinker, 1994). A broadcast ephemeris from the satellites enables the GPS receivers to make real-time positioning computations with an accuracy on the order of 50 meters.

The two ways to measure distances with a GPS are pseudoranging and carrier phase measurements. Pseudoranging uses PRN codes and a methodology that involves the generation of a binary frequency pattern simultaneously by both the satellite and the ground station. The receiver then determines the time lapse between when a particular

part of the pattern was generated and the time it was received. This time differential, coupled with a known velocity of electromagnetic energy through the atmosphere (186,000 miles/second), is a measure of the total distance between the satellite and the ground station. Achievable accuracies have been found to be about +/- 3 meters in the differential mode which requires a second receiver on a known control point (Trimble Navigation, 1994; Hern, 1989; Collins, 1987; Wolf and Brinker, 1994). Carrier phase measurements can also be made by a GPS to determine ranging information. There is a phase change that results from a carrier wave's travel from the specific satellite to the ground receiver. If the associated clocks are in synchronization, this phase shift can be measured to 0.01 cycle accuracy by the receiver (Brinker and Minnick, 1987; Goad, 1989). Only the last wavelength is measured and the use of simultaneously made measurements at two different satellites by the same receiver (i.e, differencing) reduces the errors.

GPS field procedures

There are several types of field procedures, and their usage depends on the capability of the receivers and the type of survey. The types used are static, rapid static, kinematic, pseudokinematic, and real-time kinematic methods. Each of these methods are based on the carrier phase measurements and employ relative positioning techniques (i.e., two or more receivers at different stations that simultaneously collect data from several satellites. Accuracies for these surveys are in the +/- 2-10 millimeter range (Ewing, 1990; Leick, 1990).

No matter the type of field procedure, it is essential that the receiver antenna be

accurately centered over the ground station. Stations must be selected with an overhead view free of obstructions. It is recommended that visibility be clear in all directions from an angle of 15 degrees to the zenith (i.e., satellites are normally observed above a 15 degree elevation angle). The highest accuracy work requires observations to be made on groups of 4 or more widely spaced satellites that form a geometric intersection at the observing station (Wolf and Brinker, 1994).

As with any measurement process, sources of error are present. A list of potential errors associated with the GPS is given below (Collins, 1987):

1. Clock errors of receiver,
2. Clock errors of satellite,
3. Satellite ephemeris errors (i.e., errors in uncertainties in satellite orbits),
4. Errors due to atmospheric conditions,
5. Receiver errors,
6. Multipath errors,
7. Errors in centering the antenna over the station, and
8. Electrical noise.

<u>Applicability to radiological surveys</u>

For many applications, the GPS is capable of providing real-time, accurate data on positioning at a relatively low cost. The systems are portable and do not require intervisibility between receivers. The GPS provides speed, accuracy, and operational capability by day or night and in any weather. Thus, they provide the most viable positioning alternative for automating the radiological process for outdoor sites. Figure 5

shows a picture of a portable GPS applicable to outdoor radiological surveys. A recent outdoor application of a portable GPS has been effectively and efficiently implemented (Wendling and Wade, 1994).

However, for indoor radiological surveys, the GPS is impossible to use for spatial determination. This is because there must be overhead visibility between the receivers and the associated satellites (e.g., four satellites for the accuracies needed). The building's ceilings and walls attenuate the frequency signal transmissions that are an imperative in global positioning. Thus, because of this inherent limitation, the GPS is not applicable to automating the indoor survey process.

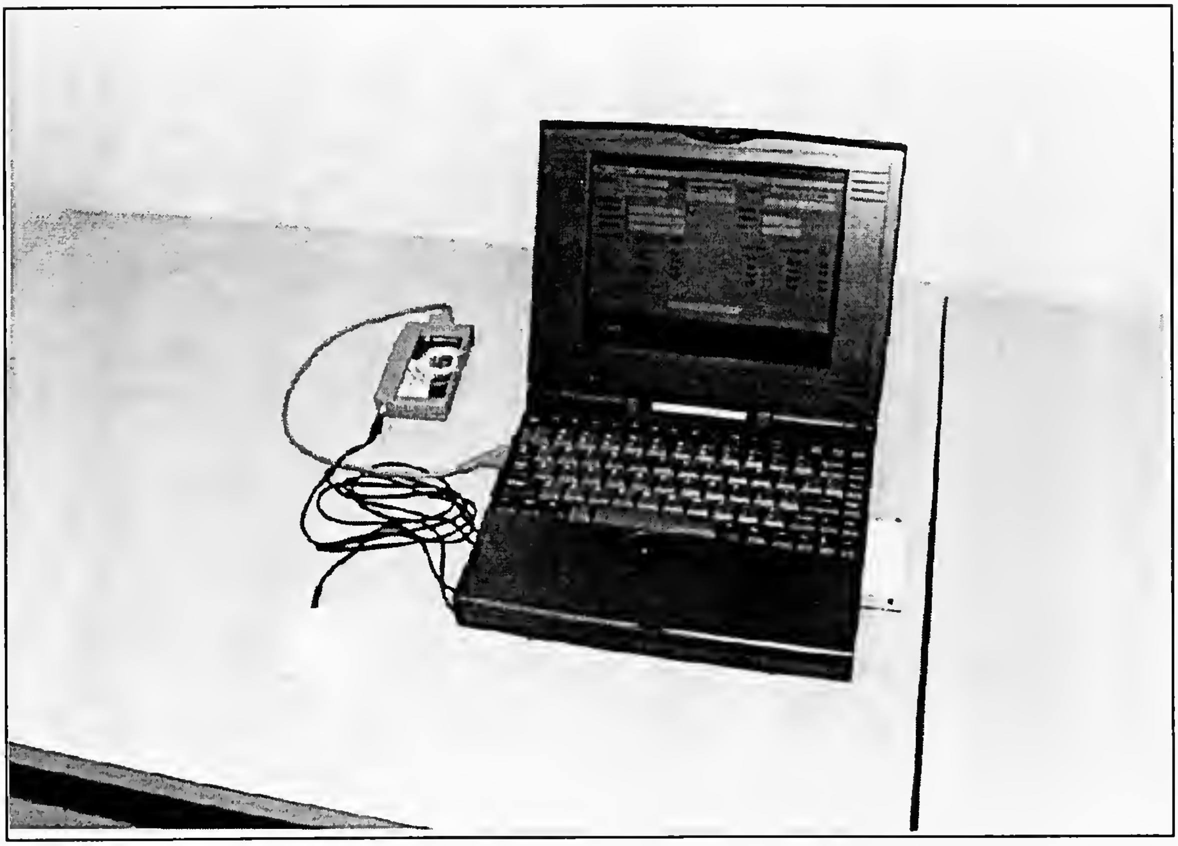


Figure 5. Portable global positioning system (GPS).

Inertial Positioning

Inertial navigation systems provide three-dimensional position, velocity, and attitude information by making measurements of acceleration over time (May, 1993; Wolf and Brinker, 1994; Roof, 1983). Acceleration and time measurements are taken in the three planes (i.e., north-south, east-west, and up-down), and the distances and directions of the instrument's movement can be computed (Wolf and Brinker, 1994; Brinker and Minnick, 1987). A traditional inertial survey system is given in Figure 6.

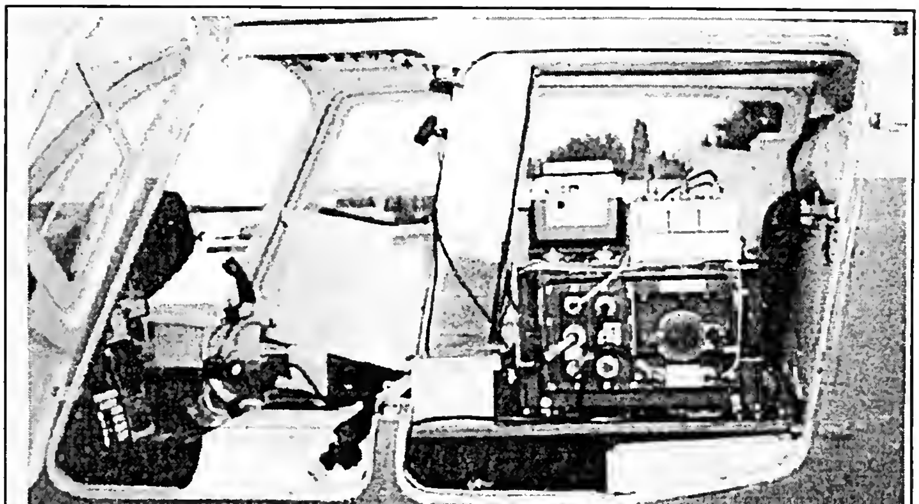


Figure 6. Traditional inertial nagivational system.

Like the GPS, the inertial positioning system emerged from military research around the time of WWII. As can be seen in Figure 6, the traditional systems were rather heavy and bulky and required movement by a land vehicle or helicopter. Today, however, there are portable hand-held systems produced by companies such as Honeywell and Rockwell.

History

Inertial navigation theory goes back to 1908 with the work of Schuler and Kaempfe in Germany. However, inertial systems similar to those in use recently were first developed in the 1930's but were not employed until the early 1940's. By the late 1960's, most military aircraft, ships, and missiles were equipped with inertial navigation systems. With the advances of the electronic/computer industry in the 1970's and 1980's, inertial systems were made smaller and smaller until land and air transportation of the systems was eliminated. Today, while still costly, portable systems are available for many possible field applications. In addition, inertial systems have been coupled with other positioning techniques (e.g., GPS) to provide system synergistics (May, 1993).

Background and theory of operation

The basic operating principle behind the inertial survey system, also known as the inertial navigation system or inertial positioning system, is the measurement of accelerations by sensing transducers as the device is moved in space. The components of a complete system include:

1. Three accelerometers to measure device acceleration in three planes,
2. Three precision gyroscopes to orient accelerometers,

3. A computer for instrument control and data storage,

4. Torquing motors and sensing mechanisms that correct for the earth's rotation, and

5. A 24 VDC power supply.

The inertial measuring unit (i.e., accelerometers, gyroscopes, sensing mechanisms, and torquing motors) is mounted on a platform to isolate it and give it precise gimbal support.

A simplified schematic diagram showing the operation of an accelerometer is given in Figure 7. Since both the mass and force associated with keeping the accelerometer static are known, the acceleration can be found by using,

$$a = \frac{F}{m}$$

where a = acceleration (ft/sec^2)
F = force (lbs$_f$)
m = mass (lbs$_m$)

Since acceleration equals the velocity divided by the time increment, measurements of the acceleration from one point to another point as well as the elapsed time will give the velocity (i.e., v = at). In addition, it is simple to determine the incremental distance traveled as well as the cumulative distance traveled by using the relationship,

$$v = \frac{dx}{dt}$$

where v = velocity (ft/sec)
dx = change in distance (ft)
dt = change in time (sec)

It is very important to initially set a reference point. Inertial navigation systems measure at very short time intervals (e.g., 0.02 seconds). The three components of movement are vector quantities, and thus, the total horizontal distance would be the square root of the sum of the squares of the components (Wolf et al., 1994; Treftz, 1981; May, 1993; Roof, 1983).

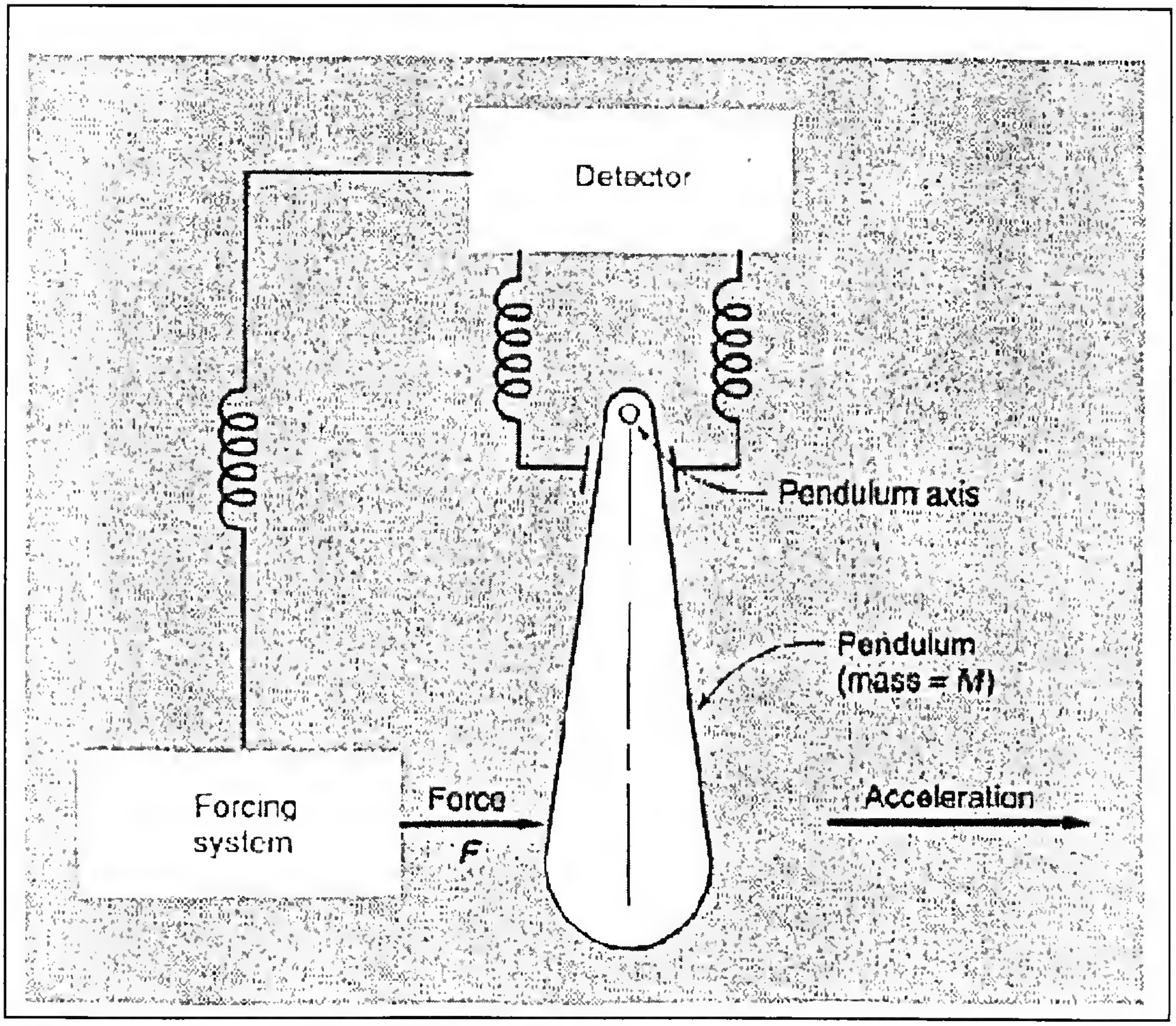


Figure 7. The operation of an accelerometer (from Wolf and Brinker, 1994).

Inertial survey system field procedures

As was mentioned earlier, the traditional inertial systems are large and bulky (i.e, 50-100 pounds) and are carried from point-to-point in a land vehicle or a helicopter. Thus, this type of survey can proceed rather rapidly.

It is necessary to calibrate an inertial navigation system every morning and this takes approximately 1 hour. The calibration procedure essentially involves the alignment of the axes. The system must be stationary during the calibration (Wolf and Brinker, 1994; Brinker and Minnick, 1987).

After the calibration procedure is completed, it is possible to run a traverse. The following is a step-by-step procedure on how to run a traverse with an inertial positioning instrument (Roof, 1983):

1. The inertial system is initialized at the control station. The latitude, longitude, and elevation of the control station are entered into the computer and serve as the survey's zero reference point.

2. The inertial survey system is positioned with the peep sight over the point.

3. The system is then moved on to each survey point.

4. The traverse loop is closed by returning to the initial station. This reveals any misclosure but there will still be associated systematic errors.

A zero velocity update (ZUPT) is the process of bringing the inertial system to a complete stand-still and observing the accelerations/velocities. If the values are different than zero, then there are systematic errors that have accumulated during the process (e.g., misalignment of accelerometers). The computer is then used to correct the readings back to zero. After the traverse loop is closed and the ZUPT corrections have been made, the

measured coordinates of the closing station are compared with its control values. The computer finally adjusts for misclosure errors and the ZUPT's for all the points (Treftz, 1981; May, 1993; Roof, 1983, Wolf and Brinker, 1994; Brinker and Minnick, 1987).

Accuracy can be increased by performing repeated runs as well as by going forward and returning backwards. In essence, there is a need to create an interlocking network with the traverse. Accuracies have been achieved at a +/- 1-3 centimeter (+/- 0.1 ft) level. For these accuracies, the movements should be from point to point in a directional manner with at least four control points. The traverses should begin at one control point and end at another control point. This prevents some of the systematic errors from occurring (Wolf and Brinker, 1994).

Applicability to radiological surveys

While the high costs associated with the inertial navigation systems limits its applicability to mainly military and space activities, there are other suitable field applications for its use. One such ideal application would be as a means for providing automated spatial data for both indoor and outdoor radiological surveys. The following paragraphs elucidate a proposed methodology for accurately determining the coordinates of a field radiological survey with an inertial survey system.

In designing a methodology for obtaining accurate coordinates for automated indoor surveys using an inertial system, provisions should be made to minimize the effects from the systematic errors associated with the inertial survey system. In most applications and for optimum accuracies, an inertial system must be capable of correcting for the earth's rotation on its axis (15 degrees/hour) and for latitudinal and longitudinal changes

(May, 1993; Brinker and Minnick, 1987; Wolf and Brinker, 1994). However, for such a small and limited travel survey as this one (e.g., 30 ft. X 30 ft. room), latitudinal and longitudinal errors are minimal. Also, since a building survey will more than likely be done at one altitude and on primarily one smooth surface (i.e., concrete, carpet, tile, etc.), the Z-axis corrections are not that crucial. However, for surveyed points on walls and internal objects, the altitudinal coordinates are necessary.

After the calibration procedure is complete (<1 hour), the traverse should begin with an initialization at a point of reference called a control station (Wolf and Brinker, 1994). In essence, this is the (0,0,0) reference point. For example, the (0,0,0) reference point for the indoor radiological survey could be in the southeast corner. It is recommended that indoor radiological surveys be gridded at approximately 1 meter locations (ORISE, 1993; DOE, 1992; Berger, 1992). In addition, an acceptable survey procedure is to sample at the intersection of these grids (Berger, 1992). Thus, a traverse could be run by walking the inertial survey system to each of these intersections, positioning its peep sight over the intersect point, and then proceed to collect a sample with a radiation-specific, direct reading/direct downloading instrument (e.g., Ludlum 2350).

The survey traverse would continue by moving on to each grid intersection until the traverse loop is closed by returning to the initial station. By returning to the original control station (SE-0,0,0), it will then be possible to determine any misclosures. However, closing at the initial control station does not reveal all the associated systematic errors which have been accumulated (May, 1993). The time required to perform a small

room survey of one run and of a statistically sound sample of around 30 points, should be approximately one hour.

As described earlier, a better method that aids in reducing the effects of the systematic errors involves the use of zero velocity updates (ZUPT's). Basically, the ZUPT process involves the periodic stopping of the traverse between sample collection points and taking the readings of acceleration and velocity at each of these points. Since the unit is at a standstill, the readings should be at zero. If readings different than zero are realized at any point, then there are systematic errors, such as accelerometer misalignment, that are associated with the survey traverse (Wolf and Brinker, 1994; Brinker and Minnick, 1987; Root, 1983; Treftz, 1981). Even though the addition of ZUPT's to the survey traverse will increase the time for the survey process to approximately two hours, accuracies have been attained at the 1 centimeter level, with one minute time intervals between ZUPT's).

When the traverse loop is closed and corrections have been made for zero velocity updates, the measured coordinates/elevation of the closing station are compared with the control reference values. At this time the final errors in misclosure and ZUPT are corrected for by the computer for a final spatial reading of (0,0,0).

Increased accuracy and a further reduction in error terms can be realized by modifying the survey traverse scheme. Increased accuracy can be attained by repeating the runs if time allows. The progression should follow a forward-backward technique that is used to create an interlocking network between control points, ZUPT's, and sample points. A method involving movements from point to point should be directional and three to four designated control points are recommended (Brinker and Minnick, 1987).

To prevent additional systematic errors from occurring, traverses should begin at one point and end at another. Redundancy in directional point sampling should obtain a level of accuracy of around one centimeter. However, time constraints in performing the survey and positional traverse as well as the necessary positional accuracy desired will determine if this modified scheme is viable.

The data collected from each grid point will be collected by the inertial survey system's computer. In addition, it is now possible to collect data with a notebook computer that has a data acquisition board and associated software (National Instruments, 1994; Microsoft Visual Basic, 1994). If accuracy levels dictate the need, the real-time data acquired by the notebook computer will be modified after all the systematic errors have been corrected for at the end of the traverse. Field conditions, accuracies attainable, and time constraints might require that the positional data not be downloaded to the notebook computer until the completion of the traverse. In addition, this could also depend on the data processing of the inertial survey system unit.

From the procedure presented in the last several paragraphs, it is evident that the inertial survey system would provide an ideal way to resolve the spatial component of the automated radiological survey process. However, the cost of a portable system is around $30,000 (Honeywell, 1994), and thus, limits the use of the system for most surveys. In addition, while the traditional systems are less costly, they are too bulky to move around the limited spaces associated with indoor radiological surveys.

Ultrasonic Ranging

Ultrasonics has been used for several years to determine the distance from a source to a target. Basically, ultrasonic ranging can be considered a pulse method. The pulse method involves the transmission of a short, intensive signal by an instrument to a reflector (e.g., wall) and then back again to the instrument (Rueger, 1989; Polaroid, 1994; Blitz, 1971). A common inexpensive device that operates on this principle is the digital ultrasonic range finder that is used by real estate sales personnel, real estate appraisers, and contractors to quickly find the dimensions of a structure.

History

Distance meters, employing the pulse method, first appeared on the market in the early 1980's. Pulsed distance meters for traditional survey techniques were pioneered by the Eumig Company. They released the Geo-Fennel FEN 2000 in 1983. Around this time, low-cost ultrasonic range finders were released for commercial purpose. In the mid-1980's, environmental field systems were developed that utilized the pulse principle in the form of ultrasonics to automate the navigation process in outdoor scenarios (Berven, 1991; Rueger; 1989; Chemrad, 1992).

Background and theory of operation

The distance between two points can be measured via the speed of sound in air, and a position in space can be computed by measuring the reception delay of a sound pulse to microphones of known locations (Berven et al., 1991; Rueger, 1989). Emitted sound waves travel outward in a circular fashion from the source. The time delay can be

measured and the subsequent position computed by using three or more reflectors.

Measuring the flight time between the emitter and the reflector can be represented mathematically as (Rueger, 1989):

$$2d = c(t_R - t_E)$$

where d= distance between instrument and target
c = velocity of sound in a medium
t_R= time of arrival of returning pulse, timed by gate G_R
t_E= time of departure of pulse, timed by gate G_E

The principle behind the operation of a pulse distance meter is illustrated in Figure 8. It can be discerned from the above equation that the accuracy of the distance measured by an ultrasonic range finder is directly dependent upon the accuracy of the flight time measurement.

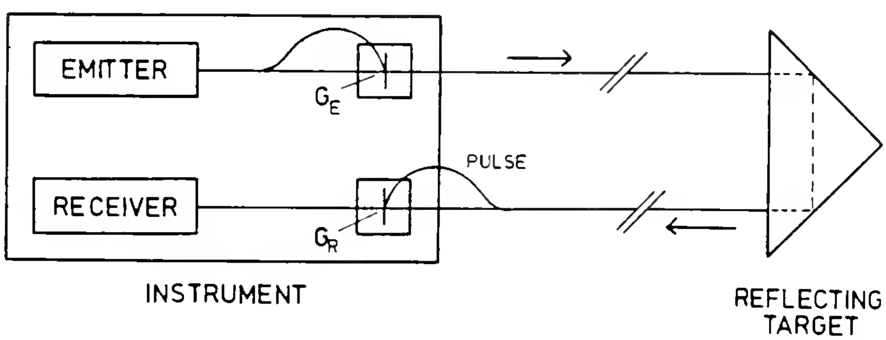


Figure 8. The operation of a pulse distance meter (from Rueger, 1990).

The two major components of the ultrasonic ranging system are the drive electronics and the pulse transducer (Polaroid, 1994). As in all pulse ranging techniques, the operation of an ultrasonic range finder involves the transmission of a pulse toward a target and the detection of the resulting echo. For ultrasonic pulsing, the velocity of the signal is approximately 340 m s^{-1}. The transducer and associated drive electronics work together to provide a measurement of the elapsed time between the start of the transmitted pulse and the reception of the echo pulse. By recognizing that the speed of sound in air is 340 m s^{-1}, a properly calibrated system can convert the elapsed time into a distance measurement. In essence, since the velocity, V, is a known and the elapsed time, dt, is measured, the relationship, V=ds/dt, can be used to find the distance, ds.

The components of a typical ultrasonic ranging system are shown in Figure 9. The drive electronics for the system shown in Figure 9 include:

1. A power interface circuit,
2. A system clock,
3. A digital section, and
4. An analog section.

The transducer acts as both a loudspeaker and a microphone and usually works on one of two principles: electrostatics or the Piezo-electric effect.

The digital electronics set the drive frequency at an acceptable level (e.g., 16 pulses at 52 kHz), and system functions such as blanking time, analog gain control, repetition rate, and detection circuitry are all generated here by a compatible microprocessor. Typical analog circuitry, used in an ultrasonic ranging system like this

one, would be a variable gain-variable Q system. The amplifier in the analog circuit is used to provide tailored sensitivities over the entire ranging of the system (i.e., higher amplification for distant echoes and lower amplification for closer ranges). This is necessary because the return signal strength is much weaker at longer ranges (e.g., the echo signal power at 35 feet is a million times weaker than that at 3 feet) (Polaroid, 1994; Texas Instruments, 1989; Intel, 1992). There are several design parameters as well as physical factors that must be considered when developing and using ultrasonics for spatial determinations. These considerations include transmission frequency, sample rate, blanking period, gain control, temperature, humidity, targets, accuracy, and resolution.

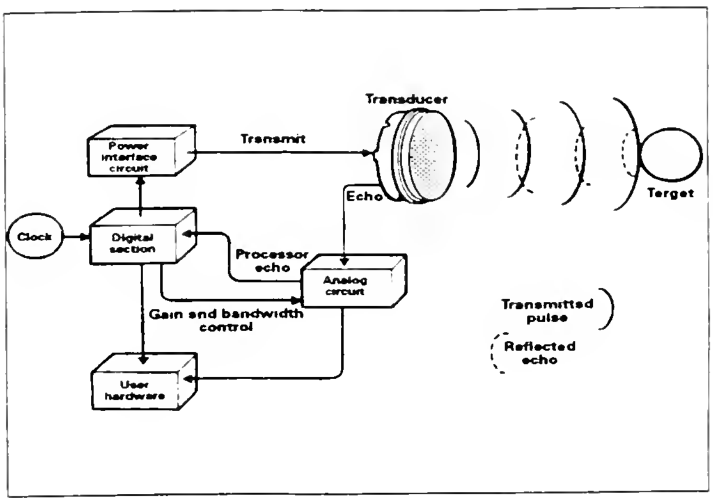


Figure 9. Components of an ultrasonic rangefinder.

Altering the transmitter frequency can provide a wider beam angle at lower frequencies and a narrower beam angle at higher frequencies (Broch, 1973). Thus, at lower frequencies, less signal attenuation would be expected and accurate ranging distances should be extended. The higher the frequency, the more the signal attenuation. In addition, the use of a shorter wavelength signal will result in better system resolution.

The sampling rate should also be considered. The number of measurements taken per second are directly related to the number of pulses being transmitted and the distance from the source to the target (Polaroid, 1994). Both fewer pulses transmitted per unit of time and a nearer target are conducive to higher sampling rates while more transmitted pulses per unit of time at a slower sampling rate will provide for accurate detection of targets located at greater distances.

The blanking period of a pulse method is the elapsed time that results from the inhibition of the acceptance of an echo signal received after transmission. This is an error term and is governed by the number of pulses transmitted and the length of time that the transducer rings after transmit (Rueger, 1989). For longer targets, an increase in blanking time will help to evade the attenuation of the signal by closer objects. In addition, when ranging to farther targets, increasing the pulses transmitted and the frequency of transmission should increase measurement accuracies (Polaroid, 1994).

For pulse ranging systems, gain control is essential (Aeschlimann, 1974). This is because close targets require less signal gain while farther targets need more signal gain. For an ultrasonic ranging system, the gain is varied over time to help compensate for signal attenuation and to minimize noise effects (Rueger, 1989).

The temperature of the air at the survey site could adversely affect the accuracy of the spatial determinations. This is because the speed of sound in a medium changes with the temperature (Kinsler and Frey, 1962; Blitz, 1971). To improve the accuracy of the measurements, temperature compensation should be included. It is possible to use a fixed target in a near field and at a known temperature to take a reference reading that will subsequently be used to make temperature compensated adjustments (Polaroid, 1994). The relative humidity will also affect the signal attenuation level. Signal attenuation goes up as relative humidity is increased to a maximum of RH=55% and then levels off.

The type and geometry of the target will affect the resolution and accuracy of the measurement. The ideal target is one that is large, smooth , hard, flat, and perpendicular to the transducer (Polaroid, 1994). This type of target will reflect the most energy back to the transducer. An object of irregular shape can disperse signals. For indoor radiological surveys, walls and flat pieces attached to survey tripods provide the best target objects. For outdoor environmental surveys, stationary receivers with smooth and flat target surfaces provide the best target materials.

All of the above mentioned factors contribute to the level of system resolution and accuracy attainable by an ultrasonic rangefinder in the field. The instrument resolution, or precision, is the smallest change that can be detected (Johnson, 1993). In general, the use of a higher transmission frequency will improve the resolution of an electronic distance measuring instrument. A typical resolution for an ultrasonic ranging system is +/- 1% of the reading beyond 10 feet and better than this value within 10 feet (Polaroid, 1994). The accuracy is defined as the repeatability of a measurement with respect to a reference

standard and is usually reported with some level of confidence (i.e., 95% confidence level, +/- 3 standard deviations, etc..). Accuracy ranges normally associated with ultrasonic system are in the range of a few centimeters.

An ultrasonic rangefinder with an analog output can be purchased for $350 and up. Those without an output can be purchased for much less (e.g., $75). Thus, a positive attribute of the ultrasonic rangefinder is its relatively low cost when compared to other positioning devices. However, as has been discussed, the signal attenuation realities associated with ultrasonic technique are a big drawback. Figure 10 provides a graph of ultrasonic signal attenuation versus target distance.

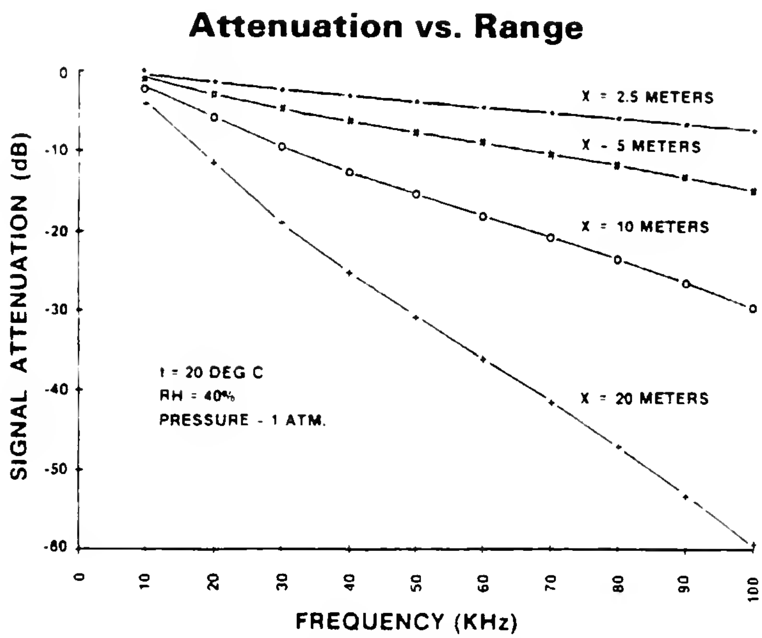


Figure 10. Ultrasonic signal attenuation versus target distance (from Polaroid, 1994).

Applicability to radiological surveys

Ultrasonic ranging has been used successfully to automate the spatial component of the outdoor radiological survey (Berven et al., 1991; Chemrad, 1992). In addition, a new system has recently been developed to perform automated radiological surveys at indoor locations (Chemrad, 1994). This system also uses ultrasonics to determine the positioning component of the survey.

USRADS was developed in the mid-1980's to collect radiological measurements and positional data simultaneously at outdoor decommissioning sites. Ultrasonic ranging was used to locate a field surveyor on a particular site and radio frequency signals were utilized to transmit the data. The surveyor's position, within an accuracy of 10 centimeters, was sampled each second. The ultrasonic signal was emitted from the backpack carried by the surveyor, and the sound was received by three stationary receivers. The position was computed by finding the intersection of the relative sound-wave circumferences. A computer drawn schematic of the property was generated beforehand, and the positions of the three stationary receivers were located. The time delay is measured between the backpack (source) and stationary receivers (targets). Then, the relationship between velocity, time, and distance was used to determine the spatial data.

The INRADS system is supposed to provide an enhancement to the USRADS by making it possible to perform automated surveys at indoor sites. Since it is a new development, a complete field implementation of this system has not yet been performed. Both systems will be further elucidated later on in this chapter.

While ultrasonic ranging has been proven to provide an inexpensive means for automating the survey process, there are still several inherent problems with these systems that limit field applicability. For one, these systems have limited measuring distances. Over longer ranges, the sound signal spreads out and bounces off nearer surfaces. The sound waves are then attenuated and reflected by these surfaces. In essence, if there is not a visible line of sight between the object and the sensor, the results will be erroneous. This is an extremely troublesome reality for indoor surveys because of the many surfaces encountered (walls, equipment, instruments, etc..). Instrument ranges are limited to around 50 feet, and building corners provide major measurement problems as well (Berven et al., 1991; Polaroid, 1994; Rueger, 1989).

Laser Positioning

Approximately 40 years ago, a major advancement in surveying instrumentation, electronic distance measuring (EDM) instruments, was realized. These devices resolve the distance between two objects by indirectly measuring the time it takes electromagnetic radiation of a known velocity to travel from one end of a line to the other and back again (Wolf and Brinker, 1994; Rueger, 1989). They have been used extensively by military and civilian (e.g., construction) interests.

History

Electro-optical distance meters evolved from techniques utilized for the determination of the speed of light. The first electro-optical distance measurement device

was designed and tested by Lebedew, Balakoff and Wafiada in the former U.S.S.R. in 1936. In 1943, Bergstrand developed the first geodetic distance meter ("Geodimeter"). The laser Geodimeter was introduced in 1968 and has been widely used in high order geodetic networks throughout the world (Rueger, 1989).

The first generation of EDM instruments that employed electro-optics consisted of large stand-alone devices. These devices were mounted directly on tripods. Subsequent generations of instruments were much smaller and mounted on theodolites. Theodolites are instruments similar to transits which can be used to measure horizontal and vertical angles. This arrangement enabled the measurement of distances and angles from one single setup. Horizontal and vertical distance components were measured from the slope lengths read from the theodolite (Wolf and Brinker, 1994; Brinker and Minnick, 1987).

Today, EDM instruments have been combined with digital theodolites and microprocessors. These instruments are known as total station instruments and can measure both distances and angles simultaneously. Real-time display of the measured angles and distances are possible, and field data acquisition in digital form is common. These "field-to-finish" instruments are gaining worldwide acceptance not only for their real-time data possibilities but also for their portability and field applicability (Wolf and Brinker, 1994).

Background and theory of operation

Electro-optical instruments transmit either laser light or infrared light. The signals transmitted by lasers are returned from the opposite end of the line by a passive prism reflector. Electronic distance measurement is based on the rate of propagation of

electromagnetic energy. The following equation mathematically represents the propagation of electromagnetic radiation through the atmosphere:

$$v = \lambda f$$

where v = velocity
f = frequency
λ = wavelength

The velocity of light is slowed in the atmosphere and can be corrected for by using an atmospheric index of refraction. The relationship is as follows:

$$Corrected\ Velocity = \frac{Velocity_{\ Vacuum}}{Index\ of Refraction}$$

The index value is around 1.0003 for our atmosphere. Thus, the accuracy of the laser measurement will depend on the accuracy of this index, which is dependent upon the pressure and temperature. Electromagnetic energy propagates through the atmosphere in a sinusoidal fashion. Positions of points along each wave cycle are represented by phase angles (i.e., 0-360 degrees or 0-1 wavelengths).

The distance between stations can be measured if the travelling time is found:

$$d = c(t_2 - t_1)$$

where c = velocity of electromagnetic waves in a medium (index corrected)
t_2-t_1 = time taken by the signal to travel from first to second station
d = distance between two points

It should be noted that it is very difficult to accurately assess the index of refraction along the wave path. Thus, the accuracy of the EDM is often limited by the accuracy of this index (Rueger, 1989; Wolf and Brinker, 1994; Brinker and Minnick, 1989; Owens, 1967).

Figure 11 illustrates the generalized laser EDM procedure. An electronic distance measuring device is centered over a known station by means of an optical plummet or a plumb bob. The process involves the transmission of a carrier signal of electromagnetic energy from one station to another. A precisely regulated wavelength/frequency signal is modulated onto the carrier wave. Since the target station returns the signal to the transmission station, the total travel path is twice the slope distance. Thus, in order to provide the distance from the transmission station to the reception station, the unit must first determine the number of wavelengths in the double path. It multiplies this value by the wavelength and then divides the resultant by 2 (Wolf and Brinker, 1994). The following equation mathematically represents this relationship:

$$L = \frac{(n + p)\lambda}{2}$$

where L = distance between the EDM and the reflector
n = number of full wavelengths
λ = wavelength
p = phase measurement (fractional part of wavelength)

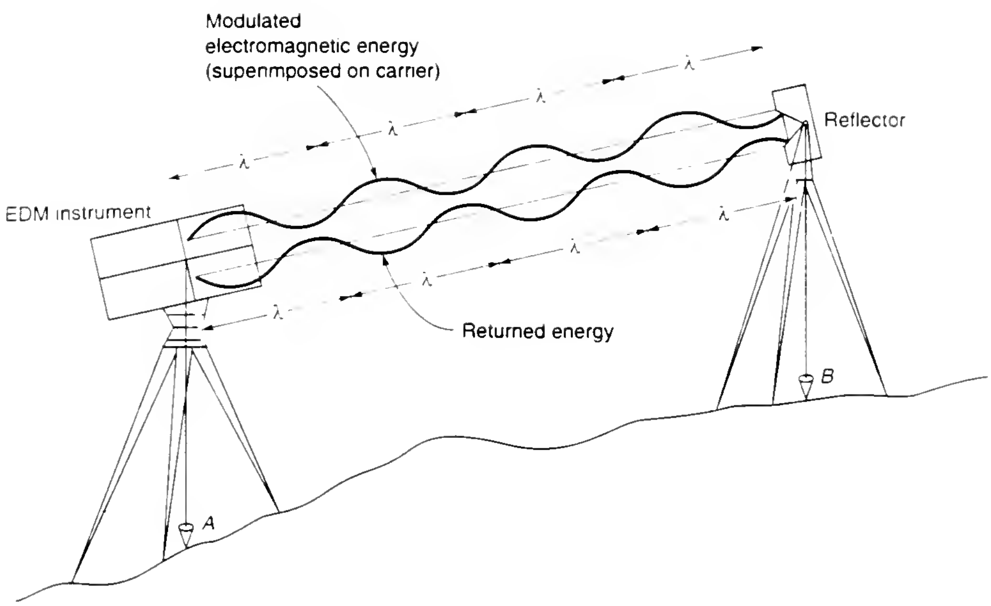


Figure 11. Laser EDM procedure (from Wolf and Brinker, 1994).

General purpose pulse distance meters can be divided into three groups. The first group includes instruments developed for use in civil engineering and industry with ranges from around 8 meters to 100 meters to matt black targets and from 8 meters to 400 meters to matt white targets. Resolutions for these instruments range from 10 to 100 millimeters. The second group of instruments include hand-held or theodolite/tripod mounted types with accuracies of +/- 0.5 meters and maximum ranges of 100 meters to passive targets and 3000 meters to single prism targets. The third group of instruments is made up of EDM types with accuracies of +/- 5 millimeters that employ the pulse rather than the phase measurement technique. The third group of EDM's have longer ranges

than the others because they can compensate the increased energy emission during a pulse with the idle times between pulses. It is possible to use EDM's to measure non-cooperative targets at close range (Rueger, 1989; Querzola, 1979; Greene, 1977).

The errors associated with laser instruments are two-fold: a constant error and a proportional error. The constant error is usually about +/- 3 millimeters while the proportional portion is about +/- 3 ppm. Due to the inherent nature of the constant error, it would be the most significant at shorter distances. On the other hand, at long distances the constant error becomes negligible and the proportional error becomes significant (Wolf and Brinker, 1994). The accuracy of laser instruments is very high except at very short distances (i.e., a few meters).

Applicability to radiological surveys

For most cases, a laser rangefinder could be used to provide positioning data for automated radiological surveys. However, since radiological surveys require positioning data at 1 meter grids or less, the accuracy of the results obtained is much less than optimum. While the constant error factor would be reduced in surveys of larger rooms or big outdoor sites, the radiological survey process would still require relatively close sampling points.

Like the ultrasonic rangefinding method described earlier, the laser system requires a clear line of sight between the source and the target. Many of the indoor sites have equipment, tables, benches, etc.. still intact, thus, causing sight problems for the laser units. If the lasers are used outdoors, it should be possible to modify the survey process in order to have clear lines of site. Thus, in comparison, the laser units would be more

appropriate for large, outdoor automated surveys than for the complex indoor surveys.

Field applicability of laser rangefinders is also limited by cost. Many of the portable laser rangefinders cost several thousands of dollars and may not prove to be cost-effective for these type of surveys. However, prices and unit size seem to be coming down substantially.

One unique advantage that the laser units provide over other methods is the ability to measure all three axes. This would provide a benefit for doing wall surveys and surveys on surfaces other than the floor or ground. The use of different overlays would not be necessary when providing the data output.

Mouse-Traverse Positioning

A relative positioning method, mouse-traverse, utilizes a common computer serial mouse to provide spatial data in the X and Y directions. A serial mouse requires a 9-pin, EIA Standard RS-232 port, which is available on most notebook computers. This positioning process involves the movement of the roller-ball on the underside of the mouse assembly. Depending on the directional movements of the surveyor, the spherical ball will rotate at it touches the survey surface. The inherent nature of the mouse provides a relative measure of the distance traversed in the X and Y directions.

Background and theory of operation

The computer mouse utilizes a technique that involves the movement of a slightly protruding spherical ball on the underside of its assembly. This ball is free to roll in the direction the operator moves along a flat surface. Inside the mouse assembly, the

spherical ball is coupled to a pair of orthogonally mounted shaft position encoders with plastic wheels. Two pairs of quadrature signals are received through the subsequent conversion of the spatial movements; one pair is used for the x-axis of motion while the other pair is used for the y-axis of motion. Thus, dependent upon the direction of these movements, the displacement information is obtained (Hall, 1992; Lafreniere, 1994).

The operating principle of the serial mouse basically involves the sending of a three-byte data package to the host computer whenever there is any resulting change in state of the mouse. A change of state is defined as either (1) any specific motion of the mouse or (2) any change in position of either of its buttons (Lafreniere, 1994). The packet of data that is sent to the host is an accumulation of all the activity of the mouse since the previous transmission (Hall, 1992). Thus, this means of "buffering" provides an integrated measure of the mouse velocity while it transmits serially at a low baud rate (e.g., 1200 baud).

The format for the three-byte data package for a typical mouse (e.g., Microsoft Mouse) is given in Table 2 (Lafreniere, 1994):

TABLE 2
Typical Mouse Protocol

BYTE #	**BIT 6**	**BIT 5**	**BIT 4**	**BIT 3**	**BIT 2**	**BIT 1**	**BIT 0**
1	1	S1	S2	Y7	Y6	X7	X6
2	0	X5	X4	X3	X2	X1	X0
3	0	Y5	Y4	Y3	Y2	Y1	Y0

For operational clarity, the following listing gives the specific components of this protocol:

1. Bit 6 is a synchronous bit and indicates the beginning of a transmission frame. Otherwise, it is reset.

2. S1 represents the state of the left mouse button. A 1 indicates the button is down while a 0 indicates the button is up.

3. S2 represents the state of the right mouse button. A 1 indicates the button is down while a 0 indicates the button is up.

4. X7 through X0 is a signed, 2's-complement integer that represents the relative displacement of the mouse in the X-coordinate direction. The value indicated is since the last data transmission and, if the value is positive, the relative mouse movement was to the right. On the other hand, if the value is negative, the relative mouse movement was to the left.

5. Y7 through Y0 is a signed, 2's-complement integer that represents the relative displacement of the mouse in the Y-coordinate direction. The value indicated is since the last data transmission. If the value is positive, then the movement was downward. On the other hand, a negative value indicates upward motion.

The mouse electronics is driven by enabling the Request to Send (RTS) line and the Data Terminal Ready (DTR) line while disabling the Transmit Data (TXD) line. By providing these settings to the three RS-232 serial port lines, sufficient power is supplied to drive its microprocessor and associated electronics (Lafreniere, 1994).

Applicability to radiological surveys

The mouse-traverse method of positioning is well-suited to surveys where only flat, level surfaces are found. Thus, it would be impossible to get accurate positioning data at an outdoor site with a mounted mouse assembly. However, for indoor floor surveys, the mouse-traverse technique may provide a low-cost alternative for automated positioning.

For example, the mouse assembly could easily be mounted to a survey apparatus, and relative positioning data could be directly read into a computer program through a RS-232 port. Since most notebook computers have only one serial port, the mouse would share time with other instruments. This could be easily accomplished by using a multiplexing device such as a data selector.

The main errors associated automated surveys utilizing the mouse-traverse technique involve the accuracies attainable on less than ideal surfaces. In addition, any deviation from straight line motion will result in X-coordinate and Y-coordinate positioning inaccuracies. However, as for the inertial positioning systems, modifications in the survey procedures can help to reduce the magnitude of these inherent error terms.

From this discussion, it is evident that the applicability of the mouse traverse method to field surveys will always be limited by its less than desirable mechanical durability. However, its availability, affordability, portability, and compatibility (i.e., it interfaces directly to notebook computers) still make it a viable option under some conditions.

Automated Contouring Systems

Automated contouring systems could be applicable to field surveys, especially in situations where elevations vary or when objects are present in the survey field. For the last decade, these systems have been used by the surveyor to characterize field terrains.

Digital elevation models (DEM) provide a digital representation in the form of a 3-

D array (Carter, 1988; Crosswell, 1988). There are two basic methods of collecting data for DEM's; the grid method and the irregular method. Irregular spaced DEM's are created from triangular irregular networks (TIN). A TIN model is a network of adjoining triangles constructed by connecting points in a data array (Wolf and Brinker, 1994). For the TIN's, there are two basic assumptions that might be made:

1. All of the triangles must have constant slopes, and
2. The surface of the triangle is a plane.

Objects or controlling features in the field can be identified by breaklines that can be generated by today's computer mapping technologies. These breaklines are developed by manual input arrays. The development of breaklines could be beneficial in characterizing the physical aspects of an indoor or outdoor survey site. For instance, indoor controlling features such as different floor levels or area equipment could be located and then represented on a three-dimensional drawing. However, if automated contouring systems are used in radiological surveys, it is essential for process reliability to select field points carefully, identify breaklines, and input the required data arrays.

A major advantage of triangular irregular networks is that once it is created for a region, profiles and cross sections anywhere within the survey area can be readily derived using the computer. Thus, survey units could be assessed independently or by aggregate. However, due to equipment limitations, the use of TIN's were not considered.

A Comparison of Positioning Methods

A comparison of all of the automated positioning methods is given in Table 3.

TABLE 3
A COMPARISON OF POSITIONING METHODS

Methods	**Advantages**	**Disadvantages**	**Comments**
Global Positioning (GPS)	Accurate, affordable, easily interfaced	Must have clear line of sight	Can't be used indoors
Inertial Surveying Systems	Accurate, zero updating, 3-axes, suitable for large area surveys	Some big and bulky, very expensive	Can be used under almost any condition
Ultrasonic Rangefinding	Inexpensive, easily interfaced, readily available, ease of use	Limited range of around 50 feet, surface attenuation, susceptible to noise	Limited to small rooms indoors
Laser Rangefinders (EDM)	Availability, 3-axes, long ranges	Must have clear line of sight, expensive	Provides 3-axes (ideal for walls and surfaces other than floors)
Mouse-Traverse Positioning	Availability, cost, portability, adaptability	Not very durable, appreciable motion errors	Must have flat surfaces to use (i.e., can't be used at outdoor sites)

Data Acquisition

Because the typical time required by a modern computer to execute one instruction is a fraction of a microsecond, many calculations can be made in just seconds. The computer can programmed to periodically sample the value of a variable, evaluate it according to programmed control operations, and then output an appropriate controlling signal to the final control element. The computer can then proceed in a loop like fashion to complete other required functions.

Up until recently, getting a sample of a real-world number into the computer was not an easy task (Johnson, 1993). This process requires a combination of software and hardware to enable the computer to read in a number that might represent some sampled variable. This overall process is known as interfacing. It is now possible to take an analog-to-digital converter (ADC) and associated amplifier circuitry to put together an interface between device and the computer system. Data acquisition systems (DAS) allows sampled variables from such sources as positioning devices and radiological survey instrumentation to be downloaded to the computer with appropriate programming.

There are many types of data acquisition systems. A generalized DAS is illustrated in Figure 12. Most data acquisitions systems are available as small modules containing the circuits in Figure 12. Recently, National Instruments developed a PCMCIA Type II data acquisition card, the DAQ-700, for the notebook computer (National Instruments, 1993). The DAQ-700 has four major design circuitries; PCMCIA I/O channel interface circuitry, analog input circuity, digital I/O circuitry, and timing I/O circuitry.

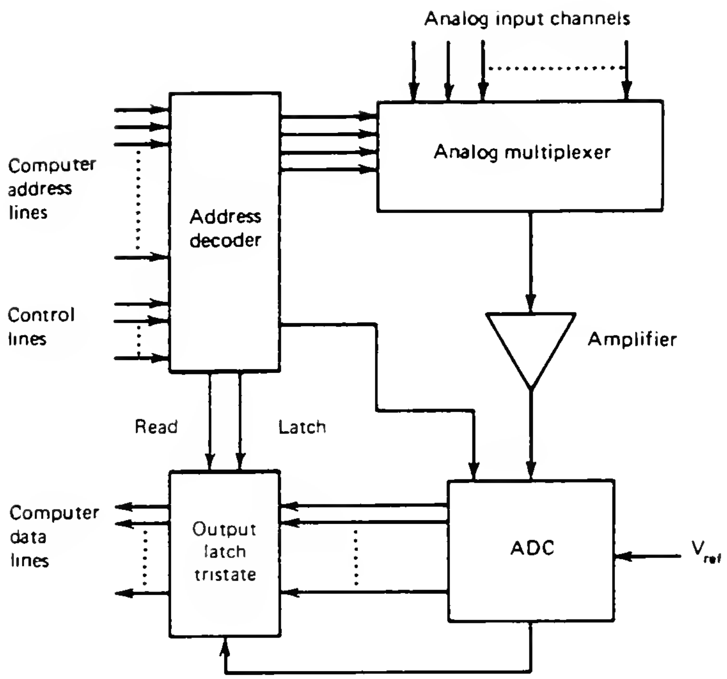


Figure 12. DAS circuits (from Johnson, 1993).

In general, the data acquisition boards accept an number of analog inputs, called channels, as either differential voltage signals or single ended voltage signals. Typically, these systems will have eight differential inputs or sixteen single-ended inputs. Resolution is usually either 8-bit, 12-bit, or 16-bit. As can be discerned by Figure 12, the major electronic hardware components of the data acquisition board are the address decoder, the

analog multiplexer, the amplifier, and the ADC. The major roles of each of these components are as follows:

1. The address decoder accepts an input from the computer via address lines that serve to select a specific analog channel to be sampled,

2. The multiplexer is essentially a solid-state switching mechanism that takes the decoded address signal and selects the data for the selected channel by closing the switch that is connected to the analog input line,

3. The amplifier compensates for the small input levels of the signals, and

4. The ADC accepts voltages that span a particular range and converts these continuous voltages to discrete, digital values.

There are a number of factors that must be addressed when utilizing a DAS. A "sample and hold" might be necessary for input signals that are changing rapidly. For example, many of the positioning techniques delineated earlier involve rapidly changing signals as the surveyor makes a traverse. Also, such concerns as compatibility, hardware programming, and software programming may become factors that must be addressed (Johnson, 1993). Another critical factor when using data acquisition boards for field survey sampling is the response time (Bogart, 1991). The time it takes the DAS to respond to a signal is important to the determination of the maximum sampling rate attainable. Slow response times could limit the timeliness of the survey process. For radiological field surveys, it is necessary to have a PCMCIA data acquisition board to interface the positioning devices and the survey instrumentation to the notebook computer. As was elucidated earlier, these boards were not available until recently (i.e., late 1993). It is very difficult to design a board that will not drain the power from the

nickel-cadmium batteries. However, the recent development of PCMCIA Type II boards such as the National Instruments DAQ-700 have provided a viable option.

Data acquisition functions on the DAQ-700 are executed by using the analog input circuitry and some of the timing I/O circuitry. The internal data and control buses interconnect the components. The board has 12-bit resolution and 16 input channels. The DAQ-700 can automatically time multiple analog-to-digital conversions. The nickel-cadmium battery can supply up to two and one-half hours of operating time. This is sufficient time to perform a survey traverse of a couple of small rooms or small plot of land. The battery can be fully recharged in less than ten minutes.

Digital Processing of Continuous Signals

Even though there are many advantages with using the computer as the control component of an integrated system, there are still some disadvantages. A serious drawback is that the transformation from continuous (analog) signals into a digital representation results in a loss of knowledge about the real value of the data.

The format of the analog-to-digital converter provides a n-bit binary representation of the value, and with n-bits it is possible to represent 2^n values. Thus, there is a finite resolution of the continuous physical data determined in a sampling (Bateson, 1973). In essence, after the continuous variable is converted to a discrete value, the exact value is not depicted. Mathematically, the relationship between the analog value and the digital representation is as follows:

$$N = \frac{(V - V_{min})(2^n)}{V_{max} - V_{min}}$$

where	N	=	base 10 equivalent of binary representation
	V	=	input value
	V_{max}	=	maximum input value
	V_{min}	=	minimum input value
	n	=	number of bits

The resolution of the sampling measurement can be found by the following equation:

$$\Delta V = \frac{V_{max} - V_{min}}{2^n}$$

where	ΔV	=	the change in voltage that produces a single bit change of N
	V_{max}	=	maximum input value
	V_{min}	=	minimum input value
	n	=	number of bits

For example, instrument detectors or positioning devices provide analog signals as a representation of a real-world value sampled. However, when these data are converted to digital numbers, some of the information is lost. In essence, a digital value will represent a range of analog numbers, and it is not possible to control a converted continuous value any closer than the resolution (Johnson, 1993).

The resolution of a system can be enhanced by using more bits. However, hardware limitations must also be considered (e.g., due to power consumption constraints, PCMCIA boards for notebook computers are limited to 12 bits). It is evident that noise can become a severe problem when automating a process. Noise can be significant when its presence increases the magnitude of the continuous signal to the point that, when it is

converted to a discrete signal, the sample value is erroneous.

For an automated survey system, the computer could be programmed to only take periodic samples of the variable value. Thus, only discrete knowledge of the continuous value is known in time. The samples must be taken fast enough to allow for the reconstruction of the data. Thus, a major issue with respect to field sampling must be the rate at which the samples are to be taken. For an automated system there is also a maximum sampling rate that is dependent upon the ADC conversion time plus the program execution time (National Instruments, 1994; Johnson, 1993; Bogart, 1992). Figure 13 shows several sampling schemes. Only (d) provides a crude representation of the analog signal given in (a).

For the automated radiological surveys that are to be performed, the determination of an appropriate sampling rate is primarily dependent upon the standard operating procedures. It is expected that this rate will not exceed the maximum nor will it be lesser than the minimum. For adequate reconstruction of the continuous signal, the sampling frequency should be about ten times the maximum frequency of the signal:

$$f_s = 10 f_{\max}$$

where	f_s	=	sampling frequency
	f_{max}	=	maximum signal frequency

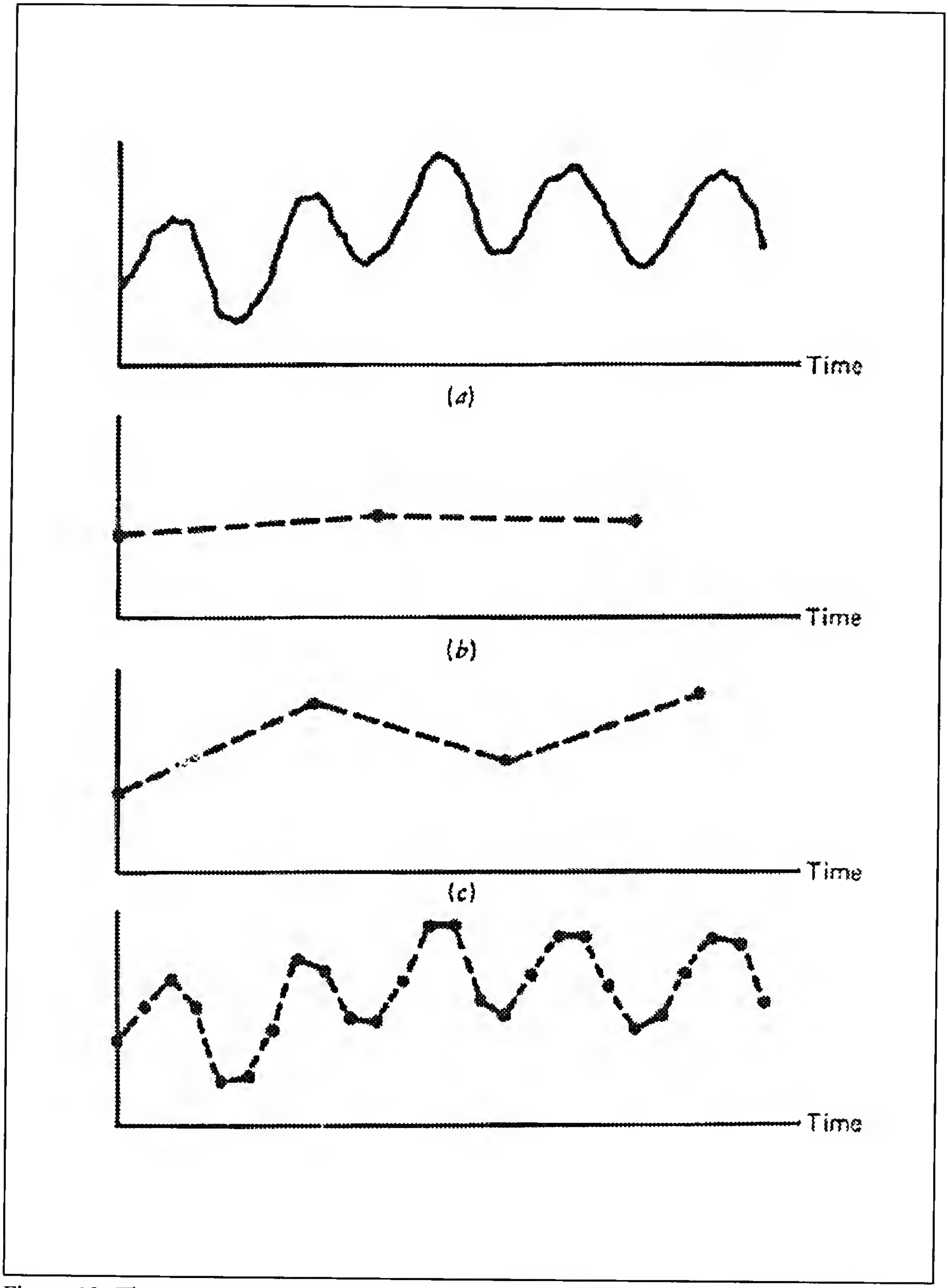


Figure 13. The construction of a continuous signal from discrete data. Parts (b) and (c) are not sampled at a rate to give an accurate assessment (from Johnson, 1993).

The sampling at grid locations and at specific points on the gridding will be selected to provide optimum resolution and digital data reconstruction. However, if the sampling scheme was such that the samples were taken continuously along the traverse, then sampling rate and resolution become more critical procedural variables.

Automated Survey Systems

Automated means of performing radiological surveys can provide faster, cheaper, and better data for site assessment (Wendling and Wade, 1994). Portable field methods of simultaneously collecting storing, and analyzing environmental survey information are now possible and economically feasible (Berven et al., 1991; Policastro, 1992). The following paragraphs delineate the capabilities of a few recently developed and implemented automated radiological survey techniques.

Mobile Gamma Scanning Van

The main objective of the mobile gamma scanning van is to provide a characterization of outdoor areas that may or may not contain residual radioactive materials (Myrick, et al., 1982). It consists of a NaI detection system housed in a specially equipped van. Since this system was developed in the early 1980's, it is controlled by an on-board mini-computer and data storage is provided by a floppy diskette unit. Multichannel analysis capabilities are provided to qualitatively and quantitatively identify specific radionuclides (DOE, 1992).

Two detector surface areas are used to accept gamma radiation. Separate energy

regions of interest can be analyzed and an algorithm that is radionuclide specific is employed to characterize the affected areas. Currently, this algorithm is specifically written to identify locations containing residual radium-bearing materials (Myrick, et al., 1982). In essence, the algorithm utilized for data analysis compares the observed count rates from both naturally and residual radioactive materials, and a "hit" criterion is used based on a Ra/Th ratio value. A hit is recorded when either the observed Ra/Th ratio is greater than the background Ra/Th ratio or when there is a positive difference between the observed Ra count and the background Ra count (DOE, 1992).

The technique that is followed when using mobile gamma scanning is as follows:

1. Establish the background rate,

2. Scans performed of suspect regions at slow speeds (e.g., 4 mph and the distance between the detectors and the properties should be minimized),

3. All accessible areas are scanned in both directions, and

4. Anomalies are highlighted by the min-computer when the "hit" criterion is exceeded.

The main advantages with this system is that it can reduce the time and cost associated in doing large-scale surveys. On the other hand, the current disadvantages include the use of outdated computer control technologies as well as specific radionuclide identification limitations. In addition, the unit is limited to outdoor surveys and, because of its nature, it is only cost effective for scans of large areas.

USRADS

The Ultrasonic Ranging and Data System (USRADS) was developed by ORNL to

perform outdoor radiological surveys. Martin Marietta Energy Systems, as the operating contractor of the ORNL for the USDOE, has subsequently obtained a patent on the USRADS. The primary motivation for the development of the system was the need to perform radiological surveys on several thousand properties in Grand Junction, Colorado, that contained uranium mill-tailings.

Basically, the system can determine radiation exposure rate and positional information to be simultaneously collected, stored, and analyzed in real-time (Berven, et al., 1991). This manner is more efficient than the conventional, manual survey techniques. The system tracks the position of the surveyor by measuring the travel time of ultrasonic pulses (approximately 20 kHz frequency) from a backpack transducer to three or more stationary receivers located in the survey area (DOE, 1992).

The USRADS set-up is illustrated in Figure 14. The USRADS locates the surveyor one time per second using the acoustical travel time from the transmitter to the receiver. These times are reported to the field computer via Rf transmissions. In addition, the radio transmitter on the backpack sends the survey reading to the field computer. The USRADS system also generates site feature maps and various graphical display formats, and the system can convert survey data files to ASCII format to be used with commercially available software packages (Chemrad, 1992).

USRADS can provide tracking in the resolution of +/- 6 inches. For large-scale outdoor surveys, it provides the survey team with the capability of high data sampling with very few interferences. However, there are some disadvantages associated with the system. For one thing, due to the inherent nature of ultrasonics, signal attenuation can

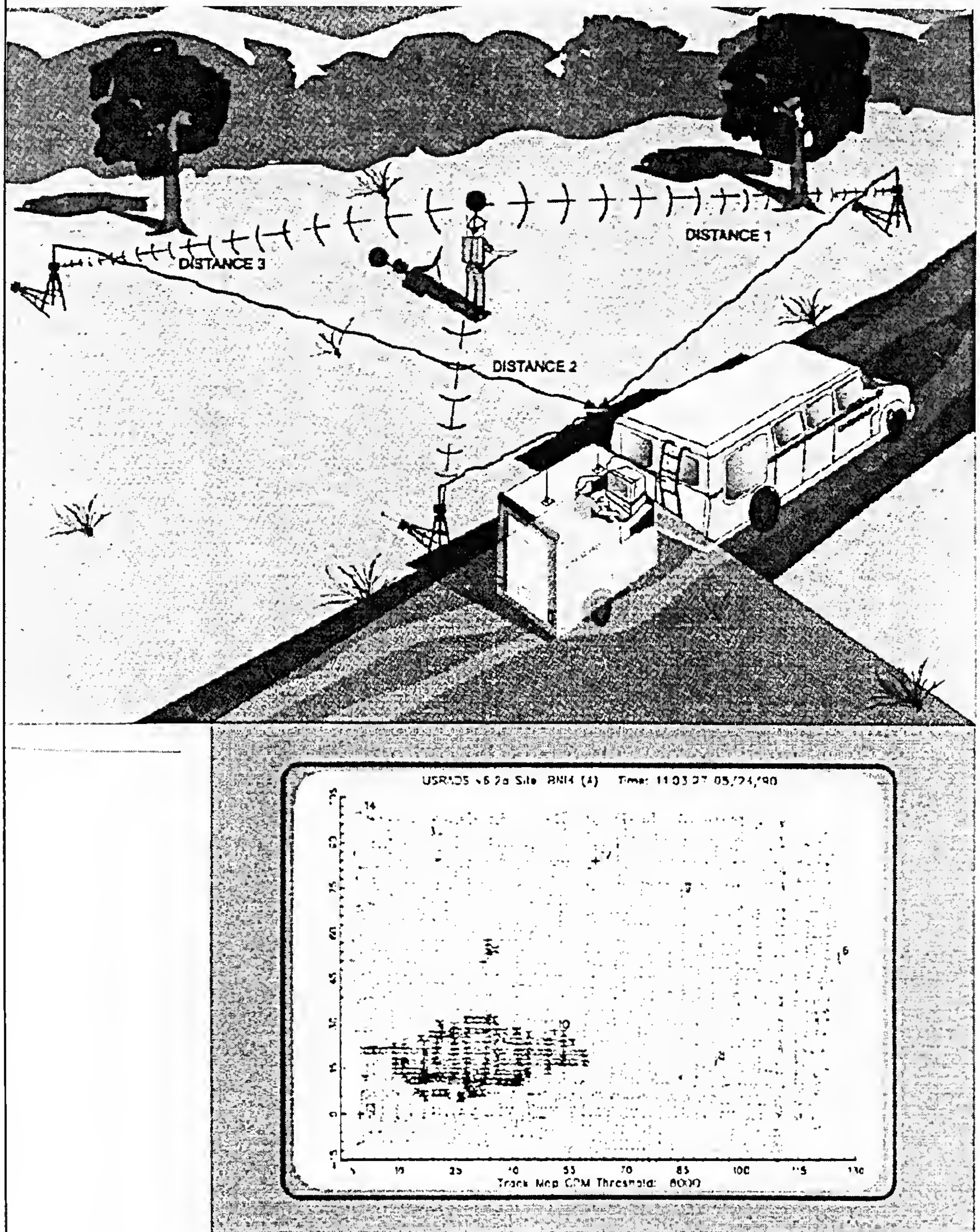


Figure 14. The USRADS unit (from Chemrad, 1992).

lead to erroneous results. In essence, objects included in the line of site between the surveyor and the tripod-mounted transducers will attenuate part of the ultrasonic signal. For indoor surveys, the interferences from objects, such as equipment and benches, would be significant. Thus, the system is not well suited for indoor surveys, especially those with rooms that are not totally vacated. Another disadvantage is the resolution of the computer-generated track maps. While these maps do provide the survey team with a display of real-time data, they are somewhat difficult to resolve.

In summary, operational experience has indicated that the USRADS unit is capable of efficiently and accurately collecting a greater quantity and higher quality of outdoor radiological survey data (Berven et al., 1991). The system requires less effort in data transcription and analysis while needing only slightly more field effort as compared to conventional survey methods. However, the current system lacks in such attributes as resolution and portability. In addition, it may not be appropriate for indoor surveys. These inadequacies have lead to the invention of the INRADS 2D.

INRADS 2D

The purpose of the design and development of the Indoor Ranging and Data System (INRADS 2D) is to provide an automated technique for performing radiological surveys on interior walls, ceilings, and floors. While its precursor, USRADS, has been effective in performing outdoor site surveys, an automated means for accurately and efficiently characterizing indoor room surveys has not been proven. Like the USRADS, the INRADS 2D determines positioning data through sound pulse transmission and

reception.

Much of the software for the INRADS 2D system has been adapted from software that has been used and proven over several years in the USRADS unit. In addition, like the USRADS, the INRADS 2D can determine and record the location of the survey detector as well as its data output each second. The data are stored automatically in a portable computer, and a real-time display of the positioning data and sampled radiation level is provided (Chemrad, 1994)

The INRADS system design includes eight ultrasonic microphones, a detector interface module, and a data interface module. The microphones are utilized as the receptors of the ultrasonic pulses. They are mounted at various locations in the room being surveyed. The detector interface module is carried by the surveyor and is used to receive the data from the radiation detector. In addition, the detector interface module transmits, via a serial cable, the data to the data processing system. The included ultrasonic crystal has sufficient power to survey surfaces as large as 30 feet X 30 feet. The data interface module is used to drive the crystal and to notify the computer of the time of each sound wave. In addition, it receives the timing signals from the microphones and provides the RS-232 interface for the detector interface module.

The software has been written to provide real-time display of both numerical and graphical data. It employs an algorithm that is used to resolve the position of the sampling points. An outline of the actual survey surface can be generated by either importing Generic CADD™ batch files or AUTOCADD™ script files or by using the software's Quick Draw option. The software also allows for a limited statistical analyses of the data

(i.e., the number of data points, the minimum, maximum, mean, and standard deviation). Finally, the software allows for the presentation of the data as single level contour maps or as color 3-dimensional type plots (Chemrad, 1994).

The positioning accuracy of the system is +/- 2 inches while the maximum range is 30 feet. Thus, for rooms larger than 30 feet X 30 feet, the usual field procedures must be modified. In essence, survey units must be surveyed independently. As of late 1994, there has not been anything written on the results of an actual field implementation of the system. However, it is currently being piloted at several indoor sites.

Rad Rover

The Rad Rover was created to help in the remediation of the environment in and around the Hanford nuclear facility. The 560 square mile Hanford site has been a dumping ground for slightly contaminated materials. To locate and map these contaminated areas, Westinghouse Hanford Company developed and put into operation a tractor-based system that uses GPS, GIS, and current radiation detection technologies to survey the site in 1993 (Wendling and Wade, 1994). By utilizing this system, the survey teams have been able to characterize elevated regions of radioactivity, and subsequently, move the contaminated soils to disposal areas. In addition, the need for work crews on foot at the Hanford site has been eliminated.

To comply with a remediation initiative instigated by the USDOE and EPA, Westinghouse Hanford built the Rad Rover system. The Rad Rover consists of a specially equipped tractor named the Mobile Surface Contamination Monitor (MSCM-II). The

MSCM II has three major subsystems: a radiation detection system/carrier vehicle, a global positioning system receiver, and a geographical information system (GIS).

The carrier vehicle utilized is an 18-ton, four-wheel drive tractor, equipped with a modified loader attached at the front end. The detectors are supported to this loader at the proper height above the terrain (Wendling and Wade, 1994). There are three pairs of detectors mounted on the header and shielded with lead. In each pair, one of the detectors is used for reference and the other is used as the main. The pulses generated within the scintillation detectors are detected by photomultiplier tubes and amplified and passed on to a radiation controller box for amplification, counting, and processing. The radiation detectors measure both gamma and beta radiation and are capable of accurately measuring radioactivity levels as low as 50 nanocuries (Wendling and Wade, 1994).

The effective viewing area under the detector assembly is 24 inches by 70 inches and the system travels at about 2 mph. This allows for a count time of 2/3 of a second. In the survey mode, alarms can be set at whatever level (e.g., above background) the team chooses and an aerosol paint-ejection system is used to mark the ground at elevated sampling locations.

The positioning technique utilized is real-time differential GPS. For outdoor surveys, the portable GPS provides the best accuracy at the lowest cost. To minimize the effects of such factors as selective availability, atmospheric perturbation, and systemic errors, the GPS corrects the messages differentially. In addition, a GIS is used to compare data arrays and mappings. The geographical area at Hanford was subdivided into distinct section referred to a operable units. The individual surveys could be analyzed

independently or, because the radiological data were in a GIS format, the individual surveys or operable units could be tied together and overlaid on site maps (Wendling and Wade, 1994).

This automation and mobilization of the outdoor survey process has provided faster, cheaper, and better radiological characterization data to help facilitate the environmental remediation efforts at the Hanford site (Wendling and Wade, 1994). The Rad Rover is a new and creative example of how to integrate the complementary GPS, GIS, and radiological detection techniques to provide for accurate and timely outdoor survey information.

CHAPTER 3
SYSTEM DEVELOPMENT

Introduction

The purpose of this research was to develop an automated radiological survey system for performing real-time site characterizations and field assessments. The initial project emphasis was placed on providing the USDOE with a viable "tool" for mastering the indoor decommissioning initiative of its 30-year compliance and clean-up goal. However, with minor changes, the unit can be used in many environmental assessments.

Rationale

Radiological surveys are a critical component of the total decommissioning effort. However, traditional methods have proven to be very time consuming. These manual methods of performing the radiological survey present very tedious and somewhat primitive recording techniques (Berger, 1992; Mann, 1994). However, in order to provide statistically-sound survey results, the field engineer or technician must sample many points at systematically determined locations (Burkart et al., 1984; Craig, 1969; Nelson, 1984). Thus, since the survey process can be very costly in time and man-hours, methods utilizing new computer technologies, aimed at improving upon field applicability, should be given due attention and consideration.

History

The need for an automated survey system became apparent during a recent (i.e., 1991) set of projects undertaken by the Health Physics Section of the Department of Environmental Engineering Sciences at the University of Florida in conjunction with Quadrex Environmental, Inc. The collaboration involved performing a radiological survey and contamination assessment at a uranium recovery operation near Tampa, Florida (Bolch et al., 1991). As a final task, the team was to prepare a plan for the decontamination and decommissioning of this facility.

The plant had been closed for several years prior to the assessment, and records indicated that overpacks of "greencake" were still in storage. Preliminary survey plans called for measurements to be taken on total gamma (μR/hr), GM contact readings (mR/hr), swipes, and media samples for specific gamma spectroscopy. Upon initial entry of the premises, the team observed that the facility was rather complex with several buildings and floors within buildings (Bolch, 1992). In addition, the available floor plans did not match the reality. The sampling locations were taken from a predetermined grid. This grid design was based and biased upon prior knowledge of the processes that occurred in the various regions. The measurement and positioning data were recorded manually in log books and later transcribed to DBaseIII™, and, subsequently, to Paradox™ (Bolch et al., 1991). In at least two cases, analysis revealed that the technicians reversed the spatial data (e.g., reversed "north" and "south").

Thus, it was evident, from the problems encountered at the site, that an automated

technique for performing the site characterization would lead to a more accurate and timely assessment. For example, some type of "autoranging" of the survey grid, completed in the preplanning process, would have enhanced the data analysis. The "autoranging" technique would have provided for more sampling in the affected areas while eliminating the "overkill" in the unaffected regions. In addition, an automated positioning device, if properly operated and calibrated, could have been used to determine the spatial information, thus reducing the spatial errors. And finally, the advantage of real-time data analysis would have made it possible for the surveyors to make judgements and evaluations while on-site. For example, a line source or a point source could have been modeled and evaluated while performing the survey.

Approach

The original conception of the automated survey system came after the survey of the uranium recovery facility in 1991. The system is shown in paradigm form in Figure 15. Based upon the experiences learned from the uranium recovery facility survey, the optimum design included many components that would comprise a totally integrated approach to the survey and decommissioning process.

For the system to be automated, it would be an imperative to have computer control. It would also be necessary to determine the appropriate software, hardware, positioning equipment, and detecting instrumentation. In addition, these components would require proper integration. Hence, in the initial planning phase of this project, it was necessary to establish selection criteria for these components.

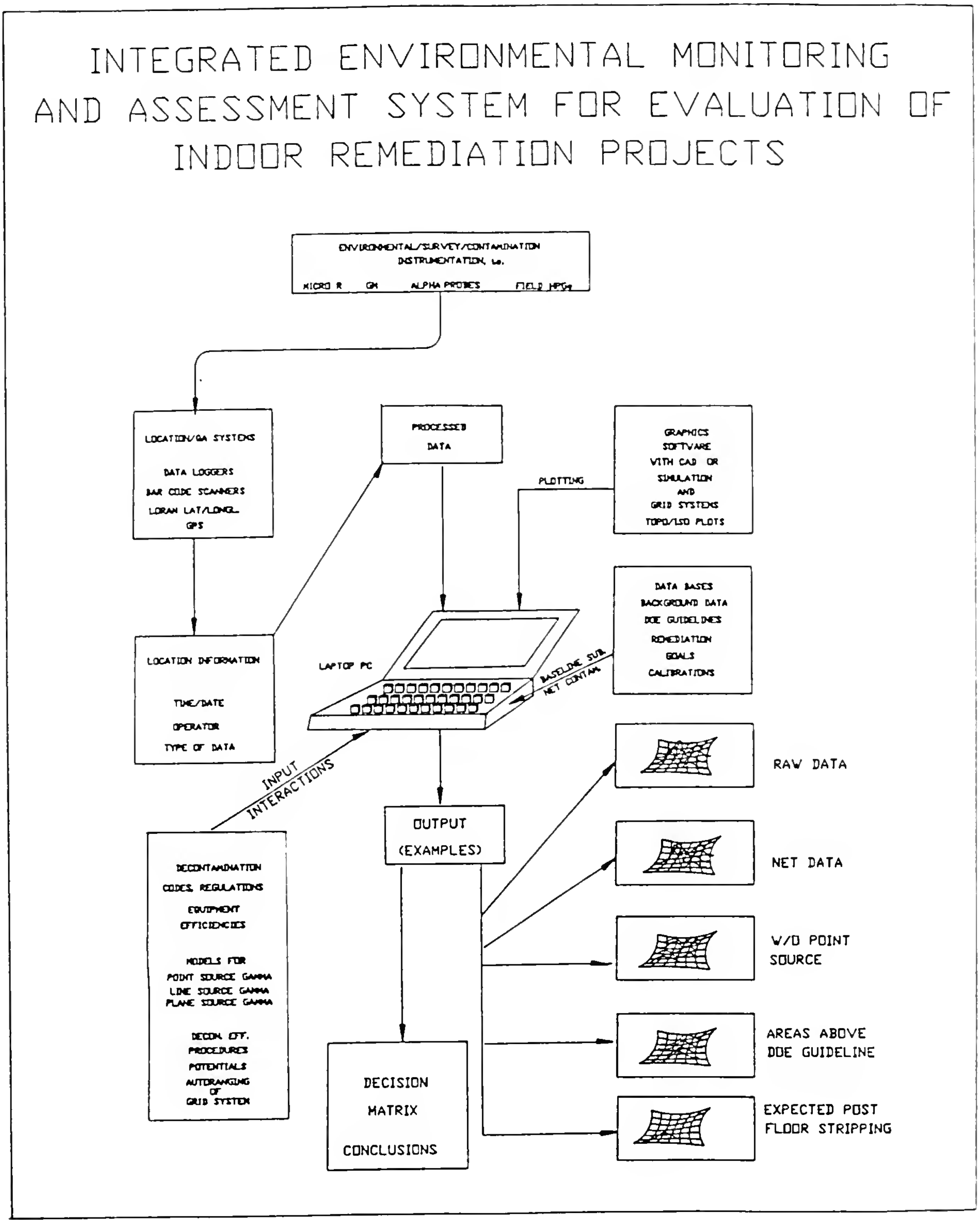


Figure 15. Original system paradigm.

Component Selection

System control

At the onset of the project, it was determined that system control would need to be accomplished with the use of the appropriate field computer. Not only does the proper computer make it possible to control, through software and hardware integration, the total system, it also provides a means for data input, output, and storage. In addition, the computer serves as the means for the total system interface. The selection of a compatible computer was narrowed down to commercially available notebooks, primarily based upon their inherent portability attribute.

Specifically, the decision was made to make the "heart" of the integrated survey system a 486 DX notebook PC. With the recent advances in both RAM and disk memory capabilities (e.g., 16MB RAM and 420MB hard drive), a notebook can be utilized more efficiently in the field than the more bulkier, traditional PC. The notebook computer is used for system control, memory capabilities, data processing, input interactions, and output generation. In addition, the notebook has a NiCd battery, which eliminates the need for AC electricity. Thus, field surveys can be accomplished in areas without AC receptacles. However, with the current technology, the NiCd battery packs require recharging after about two hours of field use. Back-up battery packs are available that could be interchanged with the discharged pack while in the field.

Several selection criteria were examined before the final selection of the system computer. For instance, in order to provide the user with high resolution graphics and

data display, the chosen computer would need to come equipped with an active matrix color screen. In addition, variety in communication options would be essential. Thus, for interfacing capabilities, the chosen notebook had one serial port, one parallel port, and two PCMCIA slots. This provides the developer and user with the needed flexibility in communications. For example, the serial port can be utilized for RS-232 communications while the PCMCIA slots can be used by instrument-specific boards or A/D cards.

Hardware

To interface the detector and positioning instrumentation to the notebook computer, a PCMCIA Type II data acquisition card was purchased. The National Instruments DAQ-700™ card was installed in one of the PCMCIA slots of the computer. The DAQ-700 has 12-bit resolution and is capable of sampling 100,000 samples per second. A connection manifold was provided with the board to allow for up to sixteen instrument connections. Since this is new technology, the board was originally sent as a "beta" prototype for evaluation. During the initial design of the board, it was discovered that the NiCd batteries were being quickly discharged by the power consumption of the board. Through subsequent circuit modifications, it now appears the board does not draw too much on the notebook's internal battery (i.e., the expected and tested life of the battery with the DAQ-700 installed and operating equals 2.5 hours).

The board provides the developer with the capability of interfacing any instrument with an analog output. Calibration and configuration are accomplished by using the accompanying software. The input ranges that the board accepts are +/- 10VDC, +/- 5VDC, and +/-2.5VDC and sixteen digital output lines make it possible to either switch external devices or generate interrupts.

Since several positioning devices have analog output ports with voltage ranges compatible to this board, it can be fully utilized as the necessary link to the computer interface. However, because of its nature, the PCMCIA data acquisition card will be a big sink for the computer's battery power. Therefore, proper allowances in the field procedures should be made to alleviate the effects.

Software

Microsoft Windows™ was the software environment chosen for the system. This decision was based on not only availability but capability. There are several Windows-based control software packages commercially available. In addition, the Windows environment makes it possible to communicate, through dynamic link libraries (DLL's) and dynamic data exchange (DDE), with many other software packages (e.g., databases, spreadsheets, graphical display packages, etc..).

The decision on what control software package to use was based on previous experience with first-generation control software such as Lotus Measure™ and LabTech Notebook™. Initially, LabVIEW™ was evaluated for its capabilities and limitations. LabVIEW is a Windows-based, control software package that utilizes "pull-down" virtual instruments as a means to build total integrated control systems. LabVIEW is a graphical programming system for developing instrument control, data acquisition, and real-time data analysis. The LabVIEW instrument library contains drivers for more than 300 GPIB, VXI, and RS-232 instruments from various manufacturers. However, the library did not include a driver for the survey instruments nor any of the evaluated positioning

instruments. For this and other reasons, it was determined that LabVIEW would not be the control program of choice. While the LabVIEW software did provide the user with a possible option for system control, it was not very user-friendly. In addition, the software program provided too much programming "overkill" for the system as designed.

The next application package evaluated was Microsoft Visual Basic™. Visual Basic provides the programmer and user with a quick and easy way to create control applications with Microsoft Windows. The software allows for the full exploitation of the graphical user interface (GUI) by making it possible for the user to draw objects (e.g., instrument buttons, gages, etc..) in a graphical way. Code is written that responds to events that occur in the interface. All system components can be integrated and controlled as one entity. Because of its applicability, low cost, and ease of use, the Visual Basic software was the control software chosen for the project.

<u>Sampling instrumentation</u>

The Ludlum Model 2350 ™ was chosen as the system automated datalogger/ratemeter. It is shown in Figure 16. The 2350 provides the ability to connect up to 16 different connectors. Thus, radiological detection of gammas, betas, and/or alphas can be easily qualified and quantified. In addition, there are up to 256 memory locations for those situations encountered that require temporary data storage (i.e., above ceilings, areas the survey apparatus can't physically reach, etc..). In addition to the acquisition of the Ludlum Model 2350, a high-energy gamma scintillation detector (2x2 NaI crystal) and an alpha/beta detector were also purchased.

The Model 44-10™ high energy gamma detector can be utilized to detect gamma

energies between 60 keV and 2 MeV. The detector efficiency is approximately 900,000 CPM/mR/hr for Cs-137 or 0.23 (23%) for a calibrated source of Th-230. The Model 43-89A/43-89B™ alpha/beta ZnS scintillator is used to detect both alpha and beta radiation. Discrimination between alphas and betas can be accomplished simultaneously via the Model 2350, which provides separate window/threshold controls for each channel. The efficiency is approximately 25% for Am-241 and 30% for Pu-239. Both the gamma and alpha/beta detector are shown in Figure 16.

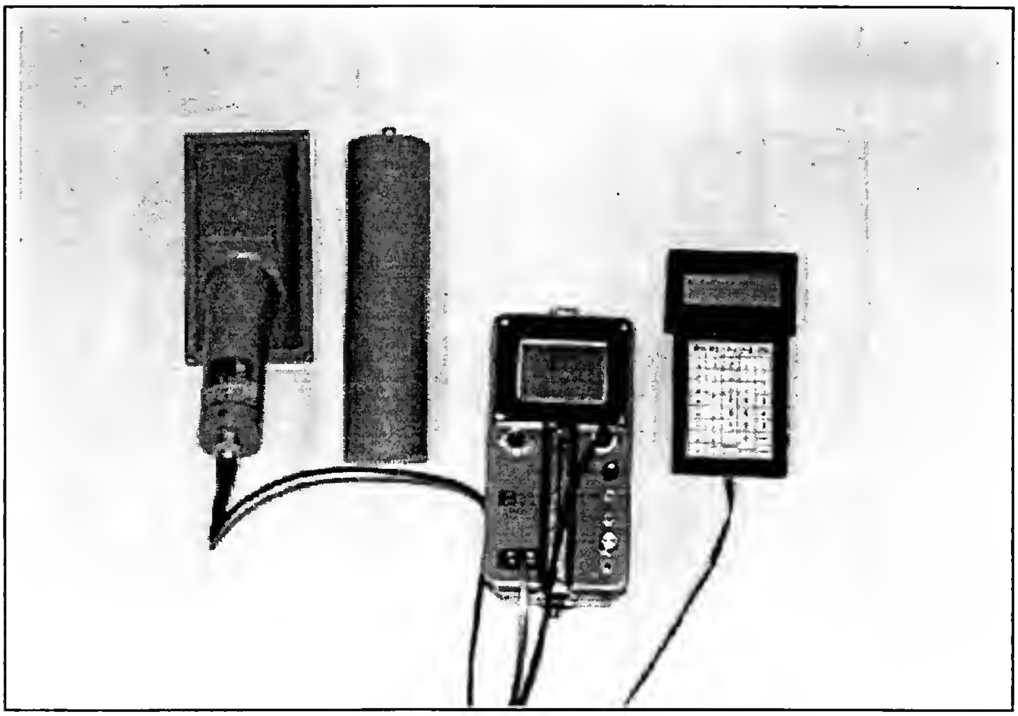


Figure 16. Ludlum Model 2350 with gamma and alpha/beta detectors.

The Model 2350 provides the latest technology in portable ratemeters. The unit can be detached from the automated system and used as a stand-alone in areas where the automated system can't be used (i.e., above the ceiling, high wall areas, irregular shaped equipment). The 2350 displays the data as a rate, scaler, or dose, and a easy calibration routine can be done on-site in a couple of minutes. The data stored temporarily in the 2350's memory can be easily dumped into the field computer.

Positioning equipment

From the beginning, it was realized that the success of the project relied mainly on the discovery of a positioning device compatible with the survey system design. The positioning device needed to come equipped with a means for communicating with the system computer. The PCMCIA data acquisition provided a way to accept an analog voltage signal from external devices while the computer had a serial communication port. Thus, the type of positioning device sought was one with either an analog output port or an RS-232 communication port.

It was determined early on that the most ideal technique for spatially automating the system for indoor surveys was by utilizing a hand-held inertial navigation system. However, the cost of the inertial unit (e.g., \$30,000) eliminated it from selection. While it could have been possible to borrow one of the early inertial models, it was much too bulky for building surveys. Another attractive alternative, global positioning, was also eliminated from consideration because it could not be used indoors. The GPS system would, however, provide a very good means for providing accurate positioning data at outdoor automated surveys. With the inertial systems and the GPS being eliminated from

consideration, the only other viable positioning alternatives were ultrasonic rangefinding, laser ranging, and mouse-traversing.

Initially, a low-cost ultrasonic rangefinder, similar to the commercially available units used by realtors or cost estimators to determine square footage, was used to provide a quick way to measure distances in the x, y, and z directions. The first unit tested was donated by a vendor and did not have an output port of any kind. Thus, the spatial data had to be entered manually during the survey. While there was discussion about taking a differential voltage signal from inside the rangefinder, another low-cost ultrasonic rangefinder was found that had a voltage output based on a distance differential. This unit, the Polaroid Ultrasonic Rangefinder™, was purchased and implemented as an automated means for resolving the spatial component. Figure 17 shows the transducer mounted on the apparatus' adjustable assembly.

Another technique, mouse-traversing, was developed during the design phase. This technique, like ultrasonic positioning, was a low-cost alternative of providing spatial data. It is a relative positioning technique that utilizes a computer trackball as the means for resolving positioning data in the x and y directions. The communication is through the serial port of the computer. The mouse-traverse transducer and assembly is detailed in Figure 18.

While the laser units could be used to provide accurate spatial data at indoor survey sites, they were somewhat limited by costs and availability. Still, some effort was made in trying to locate and obtain a portable laser unit. However, no affordable unit was found that would be compatible to the system as designed.

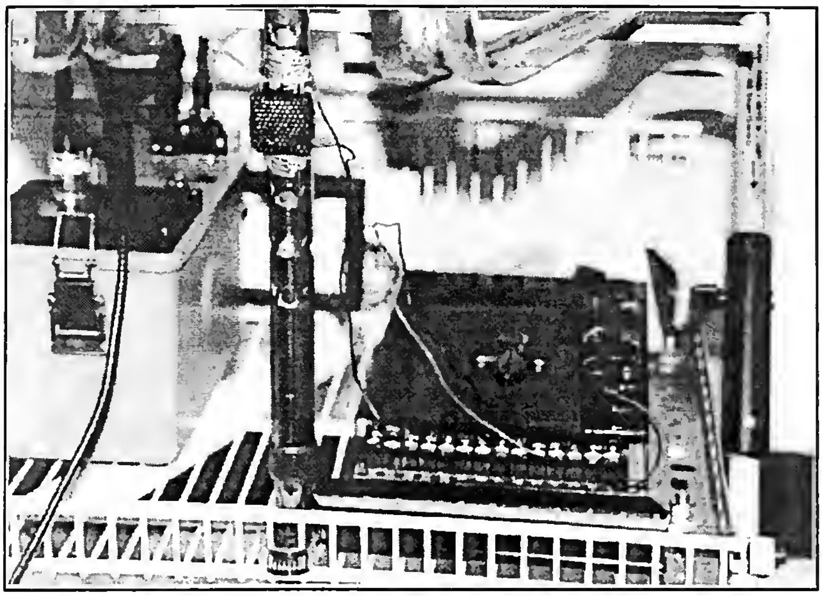


Figure 17. Ultrasonic transducer and mounting assembly.

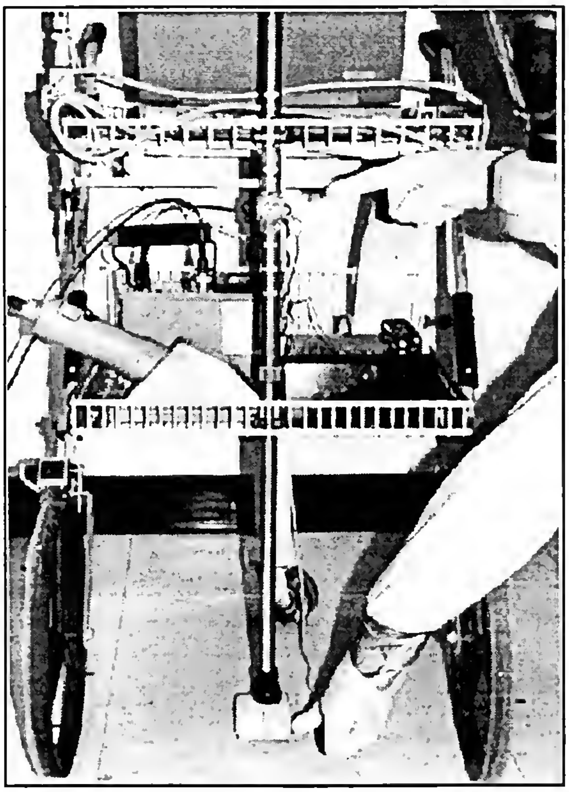


Figure 18. Mouse-traverse unit with mounting assembly.

Survey apparatus

The survey apparatus has taken on several forms since project conception. The original unit design is shown in Figure 19. This unit was designed to be used both indoors and outdoors. However, further research and recommendations by ORISE personnel resulted in a design modification that would be more suitable to indoor environments. The apparatus as originally built is shown in Figure 20 and Figure 21. The main difference between the two set-ups is the type of detector utilized. Thus, the system shown in Figure 20 was coined the GAMMAWALKER.1 while the design in Figure 21 was named the ALPHAWALKER.1. Both units have been prototyped and details are given in a later section.

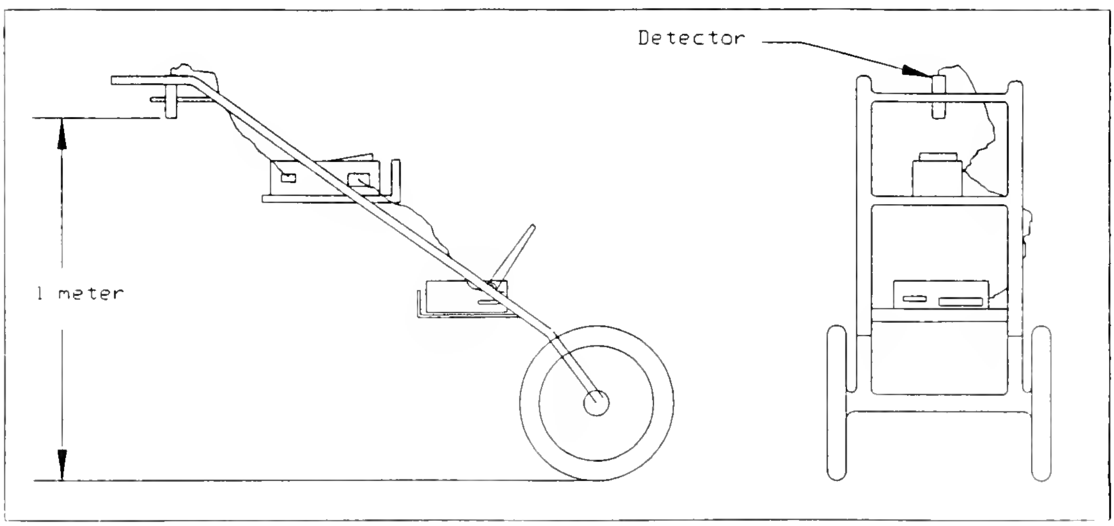


Figure 19. Original survey apparatus design.

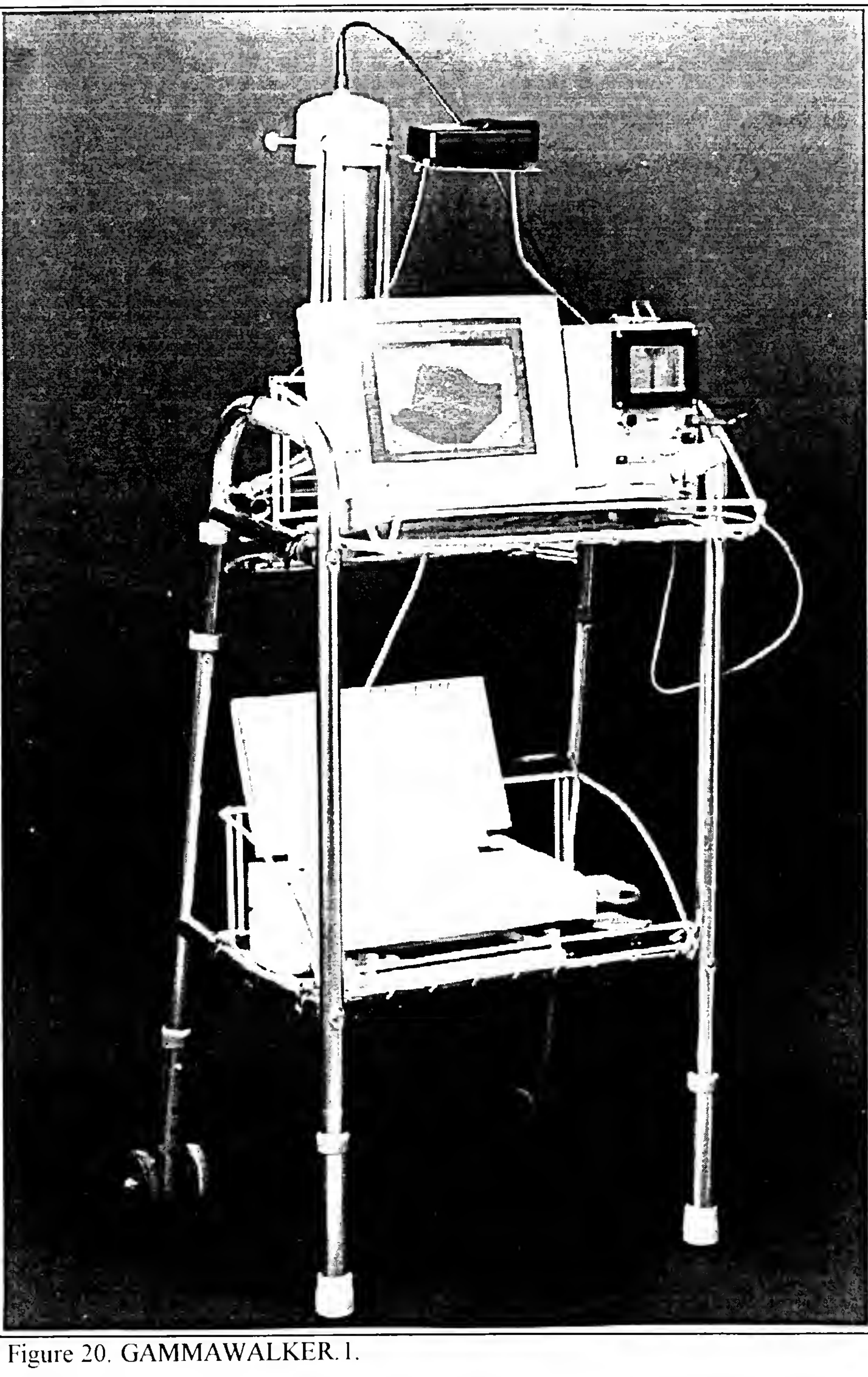


Figure 20. GAMMAWALKER.1.

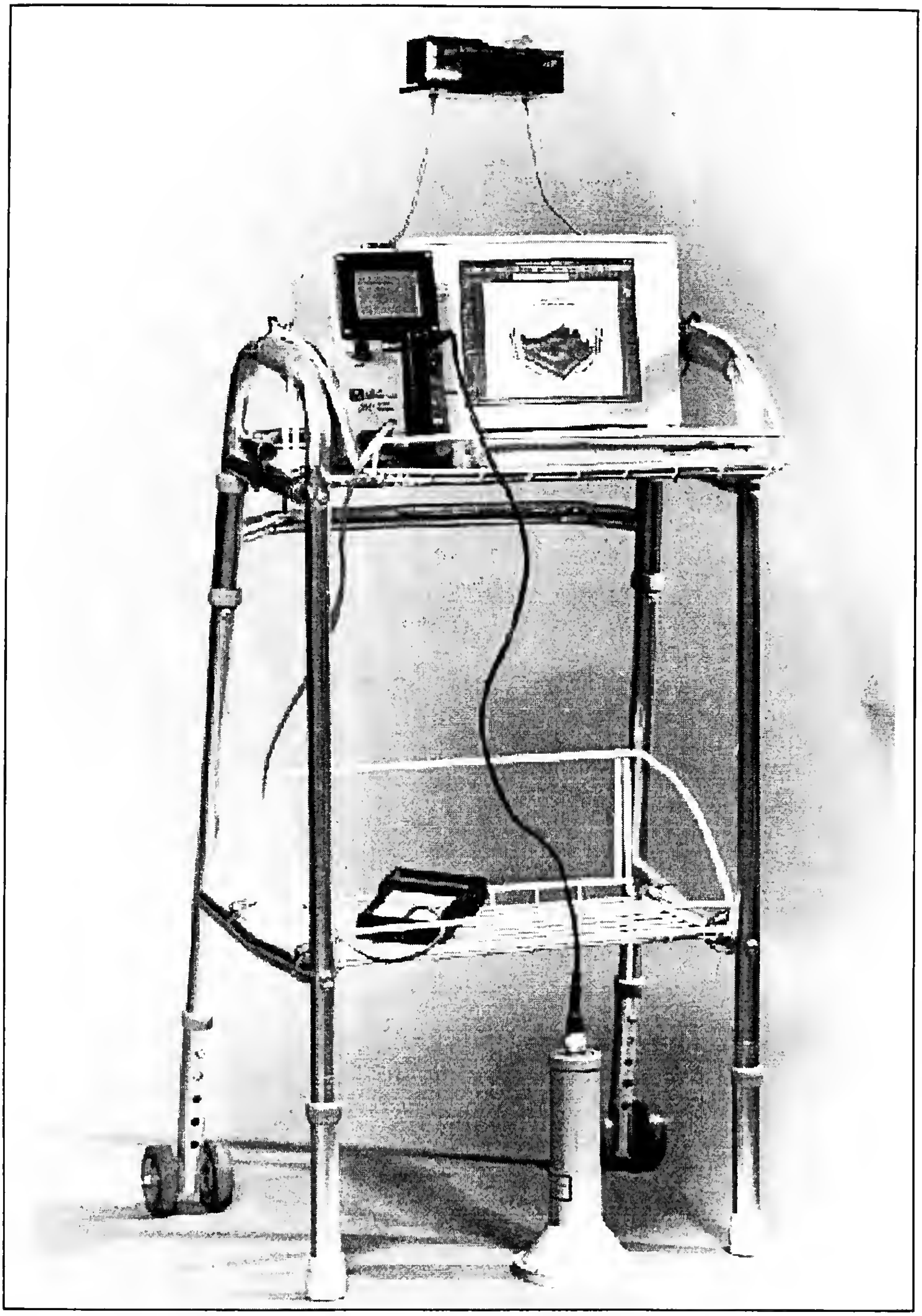


Figure 21. ALPHAWALKER.1.

The original design for both outdoor and indoor surveys was to be constructed from two calibrated survey wheels. The initial idea was to use the mechanical measuring counters on both of the wheels as a quality control check of position. In concept, the apparatus was to have two shelves; one to hold the computer and the other to provide a foundation for the detector/instrument and supporting equipment. The decision not to go forth with this development was primarily the result of discussions with survey field technicians. The field technicians thought that while the design was clever in concept, the actual unit would not be rugged enough to last very long in the field.

The "walker" design makes it possible to move around in the rooms as well as to move from one level to another. Also, its rigid structure provides an adequate means for supporting the survey equipment with little to no vibrational effects. The apparatus can be disassembled relatively easily for storage and transportation. However, as is inherent with any type of survey apparatus, the existence of width and length dimensions reduces its overall traverse mobility.

One major concern, independent of basic apparatus design, was the mounting of the positioning transducers. The transducers needed to be securely attached, but yet could not be "fixed" in location. Assurance that the transducer was accurately positioned was an imperative to spatial data integrity. However, in order to provide position and scenario flexibility, the transducer would need to be located and relocated time and time again. Thus, a detachable and moveable transducer assembly would be required. Initially, a mechanical fixture was constructed and attached to the "walker" survey apparatus that would hold the transducer, as shown in Figure 21. Also, original to the concept was a

laser pen surface detector. The laser pen was used as a means to determine the signal reception surface. The laser pen provided a quality control check for the ranging data collected.

System Integration

From concept, the proposed system interfaces are diagrammed in Figure 22. The system included, from the onset, a 486 notebook PC with a PCMCIA data acquisition card installed. Several Windows-based application software packages were installed; including Access™ for database capabilities, Stanford Graphics™ for graphical capabilities, and Visual Basic and LabVIEW for instrument control and system integration. In addition, DOS-based software that came with the Ludlum 2350 was initially installed.

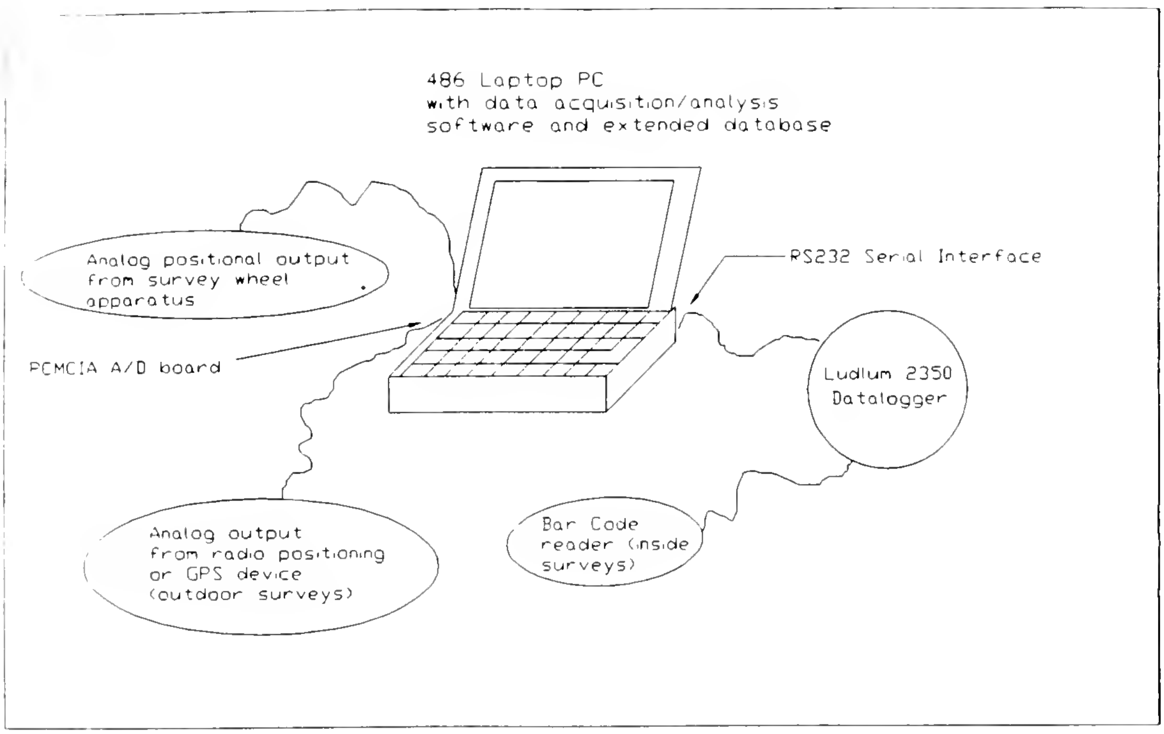


Figure 22. System interfaces.

The ultimate objective of the integration was to automatically "dump" both positioning data and instrument data simultaneously to the notebook. The notebook, through the control software, would then provide the user with real-time information about the survey traverse. Most transducers provide an analog output signal whereby the user can make the necessary interface to the data acquisition board. In addition, survey instruments like the Model 2350 usually provide some sort of output for data downloading. As mentioned previously, the Model 2350 comes equipped with an RS-232 port that can be used to dump the data via the computer's serial port. Thus, downloading the survey data from the ratemeter was never a problem. On the other hand, getting the data from the proper positioning device to the computer was a formidable task. Initially, it was difficult to locate an affordable device with an output.

As has been mentioned, several positioning devices, operating on different principles and theory, were evaluated for project compatibility. But, after much discussion and debate, it was determined that the system would be developed to allow for three types of positioning data; manual input, mouse-traverse, and ultrasonic rangefinding. While the manual input requires only keyboard entry, the other two methods provide automated means for collecting the positioning data. The ultrasonic device provides the necessary electronics for a 0-5 VDC voltage output that can be easily interfaced through the PCMCIA data acquisition board. The signal from the mouse-traverse technique, like the Model 2350 ratemeter, is interfaced through the serial port of the computer.

ORISE/DOE Meeting Comments and Recommendations

During the early stages of the project funding, a meeting with concerned parties from DOE, ORISE, and the University of Florida was scheduled to discuss project objectives and goals. The meeting was held on 9/27/93 at Oak Ridge, Tennessee. The following paragraphs provide some of the comments, recommendations, and conclusions from the meeting.

During the early stages of the meeting, the automated system was overviewed on history, rationale, approach, etc.. After this brief summary, the concerned parties were asked to provide an assessment. While the meeting attendees were impressed with the concept of the automated survey system, they did have some reservations about its theoretical design. The main project characteristic they found to be problematic was the original apparatus design.

It was concluded that the conceptual survey apparatus, shown in Figure 19, was not rugged enough for the field. It was noted that the unit needed to cover rooms the size of several acres. In addition, it was brought out that the spatial/positioning device utilized would be required to measure these large rooms, and that other automated indoor systems evaluated, thus far, have lacked in long range measurement capabilities.

Other major comments and recommendations made about the project and its design characteristics are outlined below:

1. Design system to acquire the data needed to locate the contaminated areas for clean-up (i.e., design for both decontamination and decommissioning).

2. Use Regulatory Guide 1.86 or 5480 for standards and criteria.

3. Design for instrument shielding in high contamination.

4. Seek out other sources of project funding.

5. Integrate into software decision support on cost estimating and planning, SOPs, and quality assurance.

6. Design to address different background levels for different building / materials.

As the direct result of the meeting recommendations, a complete apparatus design change was made. The survey wheel apparatus design gave way to the radwalker design, and eventual, construction. Also, as a direct result of the meeting, SOPs and quality assurance criteria were integrated into the software and database.

Pilot (Gamma and Alpha Surveys)

During the design and development stage of the system, pilot runs of both alpha and gamma surveys were completed. It should be noted that both of these pilot runs were performed only in the semi-automated mode. While the position of the sampling points was located by an ultrasonic, direct-reading device, it was still necessary to manually download the spatial data to the computer program. Manual downloading was required because an affordable and compatible ranging instrument with an analog output had not yet been located.

The automated alpha survey was accomplished while performing a thorium-232

remediation. Characterization, remediation, and final status surveys were required for all surfaces (i.e., walls, floors, ceiling, equipment, etc..) to establish a "clean" status for two indoor production rooms. For the gamma survey run, a known source was "hidden" at a location in the survey area. The objective of the survey was then to seek out and position the source. The following paragraphs elucidate the findings from these runs.

<u>A gamma "hide-and-seek" pilot</u>

A pilot run, using the set-up shown in Figure 20, was performed at a site on the University of Florida campus. A known, low-level gamma source was planted at a floor location oblivious to the surveyor. Prior to the survey, the efficiency of the detector was determined by using a calibrated source. After system calibration, the survey was completed and the data were analyzed in real-time and required no gridding. The results of the survey was constructed on a 3-D contour with the X-axis being the room width, the Y-axis identifying the room length, and the Z-axis representing the rate in micro-R/hour. The actual pilot results are diagrammed in Figure 23.

The low-level source was easily discerned on the plot at the location marked (i.e., width = 1.2meters, depth = 6.4meters), and the surveyor had no difficulty in finding the source. It should also be noted that as the surveyor approached the walls of the room, higher than average readings were observed. Thus, suggesting that the walls are made of materials that are higher in low-level, gamma source material (e.g., higher than usual uranium in the aggregates of the concrete blocks). In addition, the time component required to complete the survey was reduced several-fold over conventional methods. It took 35 minutes to complete the survey, analyze the data plot, and locate the hidden

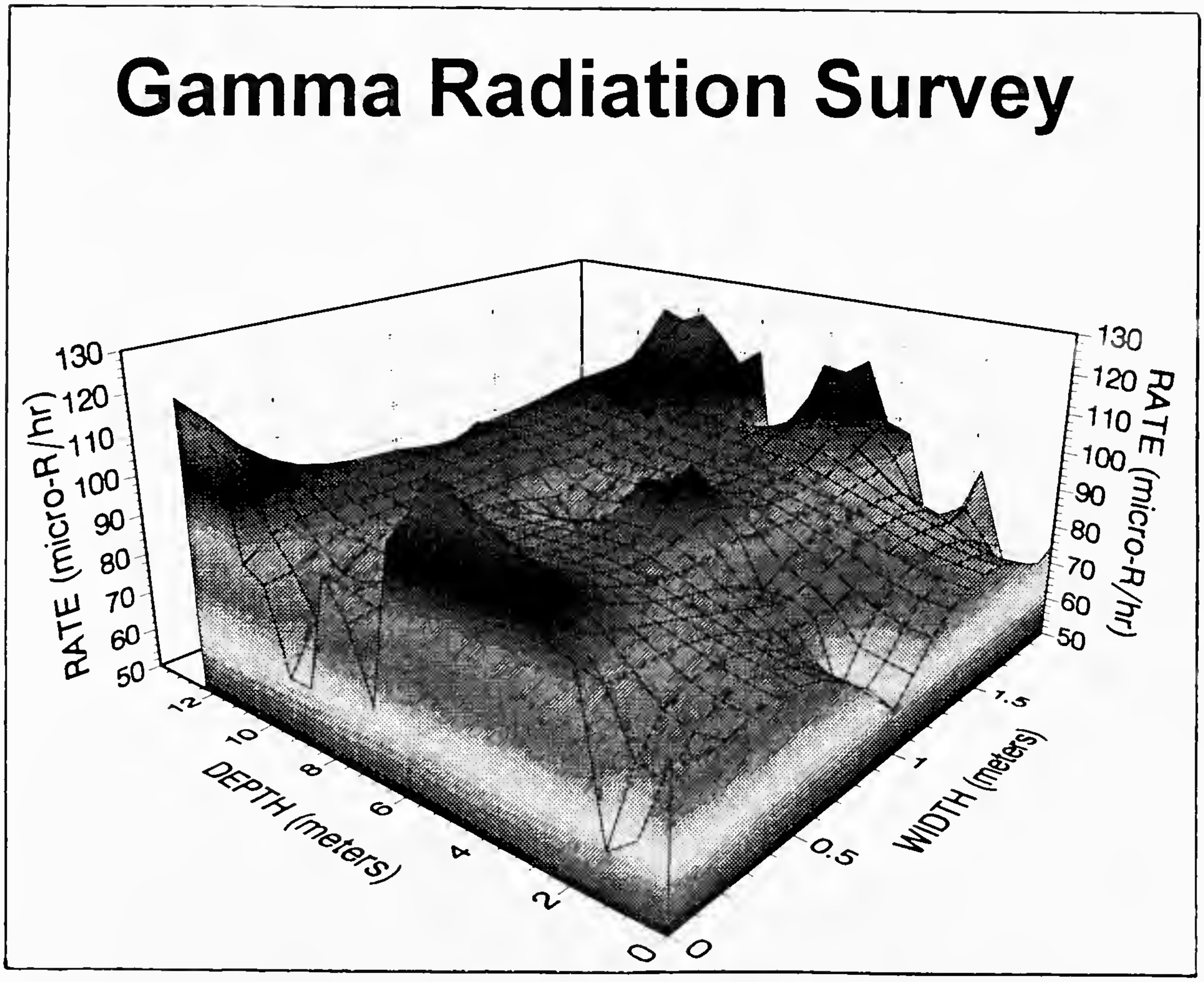


Figure 23. Gamma pilot results.

source. However, for the first time user, it should be noted that it could take several hours to learn the capabilities and limitations of the system.

A Th-232 alpha survey

A southeastern U.S. manufacturer of glasses used thorium-232, an alpha emitter, to aid in the glass-binding process. The manufacturer wanted to completely decontaminate two rooms where the materials were utilized in the process. This required both pre-decon and remediation surveys as well as a final status survey for release. The automated survey apparatus (ALPHAWALKER.1) was used to provide the necessary surveys for the decontamination project.

Prior to the survey, quality control procedures and health and safety procedures were outlined. An alpha scintillation detector was calibrated using an known source of Th-230 and the efficiency was found to be 23%. This was based on the average of five one minute sample counts of a known source of Th-230.

The project required floor, wall, ceiling, above ceiling, and equipment surveys for the two small processing rooms using the complete automated system. However, the system as designed is not appropriate for ceiling or above ceiling surveys. Thus, the surveyor used a datalogger/ratemeter to temporarily log the data points in these situations. After the completion of the ceiling/rafter surveys, the data were automatically downloaded to the computer via RS-232 communications. Figure 24 illustrates the shape of one of the surveyed rooms and the locations of the manually collected data points at or above the ceiling level.

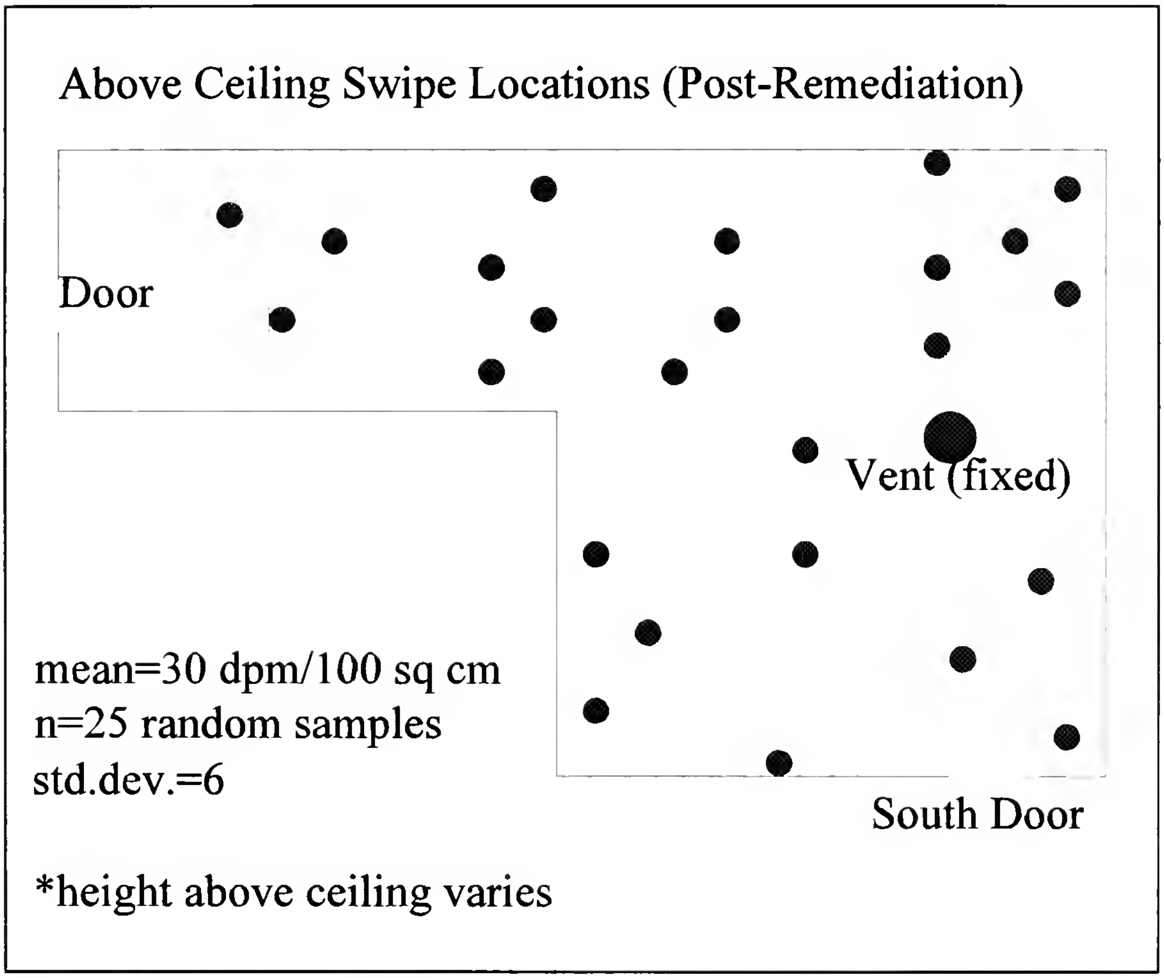


Figure 24. Ceiling sample locations.

The results from the floor survey in the main beading room are shown in Figure 25 while Figure 26 shows the results of a wall survey. A grid was laid out in approximately 1 meter by 1 meter survey units. A sample average from three readings at each imaginary grid intersection was logged as well as were the X and Y positional coordinates where the readings were taken. The upper, post-decon action level or limit was set at 50 dpm. Additional decontamination was necessary if the values attained or exceeded this value.

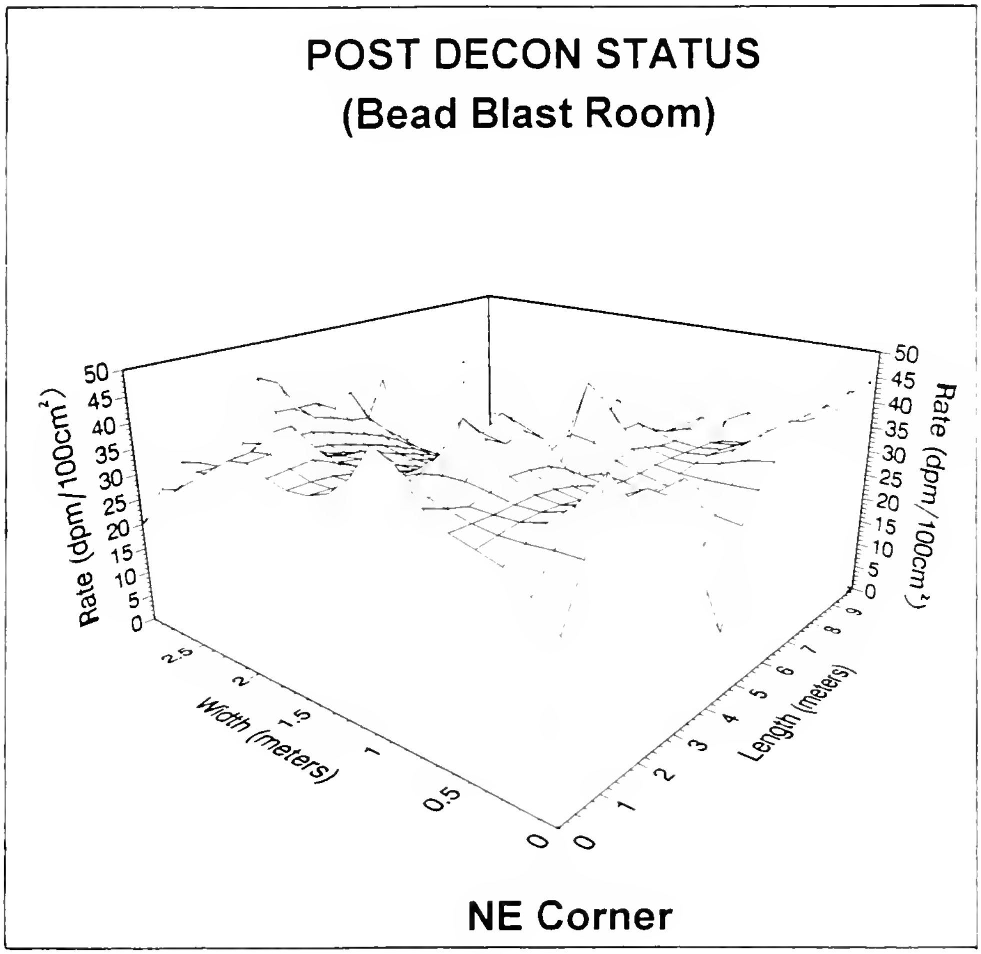


Figure 25. Results of the alpha floor survey.

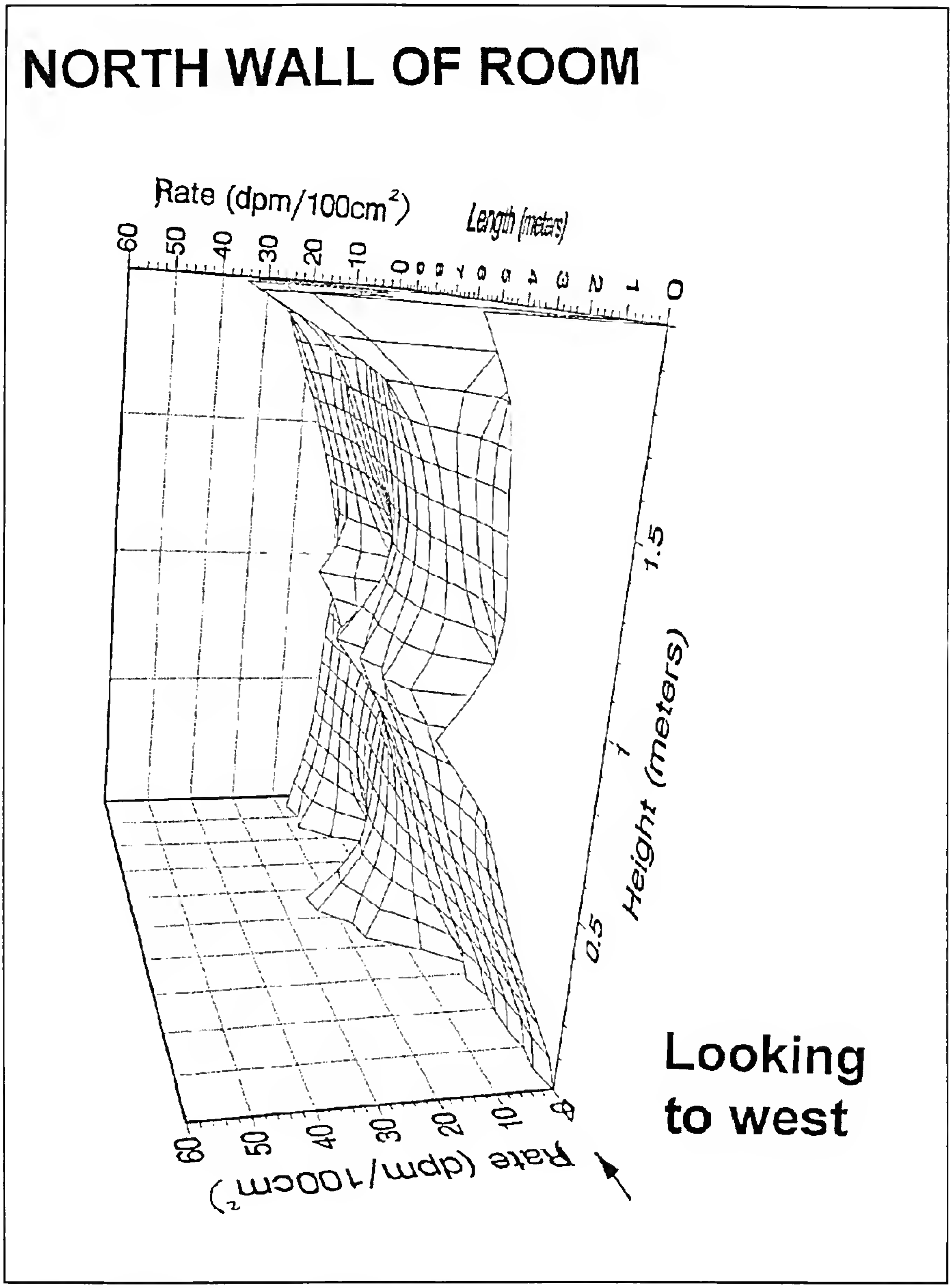


Figure 26. Results from an alpha wall survey.

The automated system alleviated the time burden associated with the survey process. It allowed for quick recognition of "hot-spots" that required further decontamination. "Fixed" radiation was located and removed (e.g., floor tiles with alphas imbedded in a rust matrix, wall paint near a fan, etc..). The final status surveys for all rooms and surfaces included 3-D contour plots of the levels at each surveyed location. In addition, the final status survey resulted in zero points above the 50 dpm criteria.

Pilot conclusions

While the pilot surveys showed that the need for manual gridding could be eliminated through the use of a semi-automated positioning technique, some problems were identified. It became apparent during the surveys that a major limitation of the system was its inability to accurately determine distances beyond about ten meters. This is an inherent limitation of the ultrasonic positioning technique. While the ultrasonic positioning technique can serve the purpose for surveys done in smaller rooms, the signal is attenuated at longer measurements. This realization brought about the further evaluation of other viable ranging methods as well as careful analysis of the operating procedures that were followed during the surveys.

A second system limitation that was identified during these surveys was the system's applicability to certain field situations. Undoubtedly, the system cannot be utilized as designed for ceiling or above ceiling surveys. Thus, almost 20% of the survey points can't be automatically located using the unit. In addition, for rooms with several pieces of equipment, the system is not very mobile. The system, while very appropriate for stripped-down rooms, cannot reach certain points effectively in "cluttered" areas. The

results of the surveys revealed the need for some system modifications to make it more applicable to adverse field conditions.

While known beforehand, a final system limitation which became evident during these surveys was the absence of an analog output on the ultrasonic device. As was discussed earlier, the ultrasonic rangefinder used provided an X and Y output only on its LED output. This LED reading had to be manually entered into the computer. Thus, crucial to the further development of the system was the locating of a positioning device capable of directly downloading the spatial data to the computer program.

Final Prototype Design

With the comments made by concerned parties (e.g., health physic field technicians, ORISE representatives, etc..) and the results from the two pilot runs in mind, a final system design and construction was completed. The following paragraphs give a detailed summary of the final system construction, its components, and their integration.

Apparatus

The final design of the survey system combines the positive attributes of earlier design efforts with the more rugged "walker" design. The final prototype of the survey apparatus, with the all of the survey equipment intact, is shown in Figure 27 and Figure 28. While the apparatus resembles the earlier design in compactness and portability, it does have an additional wheel base for stability. The total system weighs less than 30 lbs., which enhances its maneuverability in the field. In addition, the unit can fit into tight places as well as be raised and lowered to different floor elevations.

Figure 27. Final apparatus design (shown while performing a wall survey).

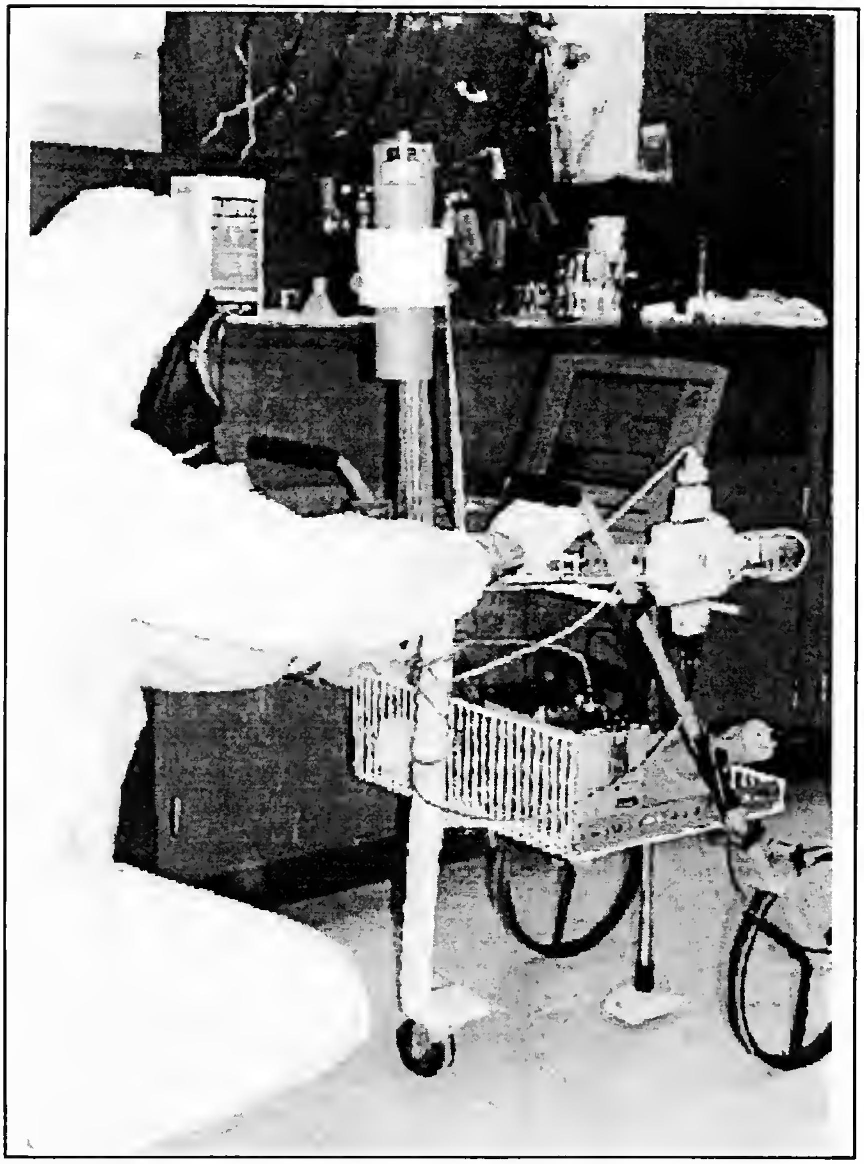


Figure 28. Completed survey system.

The two-shelf design, which has been a characteristic of the survey system from the onset, provides adequate room for the notebook computer, the ratemeter\detectors, and the necessary positioning components. An additional mount is provided for the gamma detector, which, by specification, must be mounted at one meter above the surface. The original two survey wheels came equipped with mechanical counters calibrated to one foot increments. Thus, the apparatus provides a quality control check for distance measurements. The additional wheel base provides extra mechanical and directional support, and a transducer positioning assembly provides both a mount and a means of directional control for both the ultrasonic ranging and the mouse-traverse positioning units.

<u>Software</u>

As mentioned previously, Visual Basic was the programming language adopted. Visual Basic provided the user with a means of integrating all of the system components through its graphical interface. All of the system's components could be controlled as if they were just one, integrated instrument. Forms (or screens) were developed for system configuration, background measurements, sampling with mouse-traverse positioning, and sampling with ultrasonic positioning. Algorithms were written that specifically resolved the mean, standard deviation, and 95% confidence level for each survey unit as well as the minimum detectable activity (MDA) of the total survey. To perform all of the system functions, over 8,100 lines of code have been written in Visual Basic. The following sections detail the specific forms developed for alpha and beta surveys.

<u>Configuration screen</u>

The screen developed primarily for the initial configuration of the Ludlum 2350 ratemeter/datalogger is shown in Figure 29. As can be seen from the figure, the form allows the user to input such parameters as detector dead time, calibration constant, detector efficiency, serial/part number, scales, and units. After the data have been entered for all of the parameters, the software, via Windows Terminal™, transfers the set-up data to the memory of the Ludlum 2350. The Ludlum saves these data until they are changed through the configuration task or by manual input.

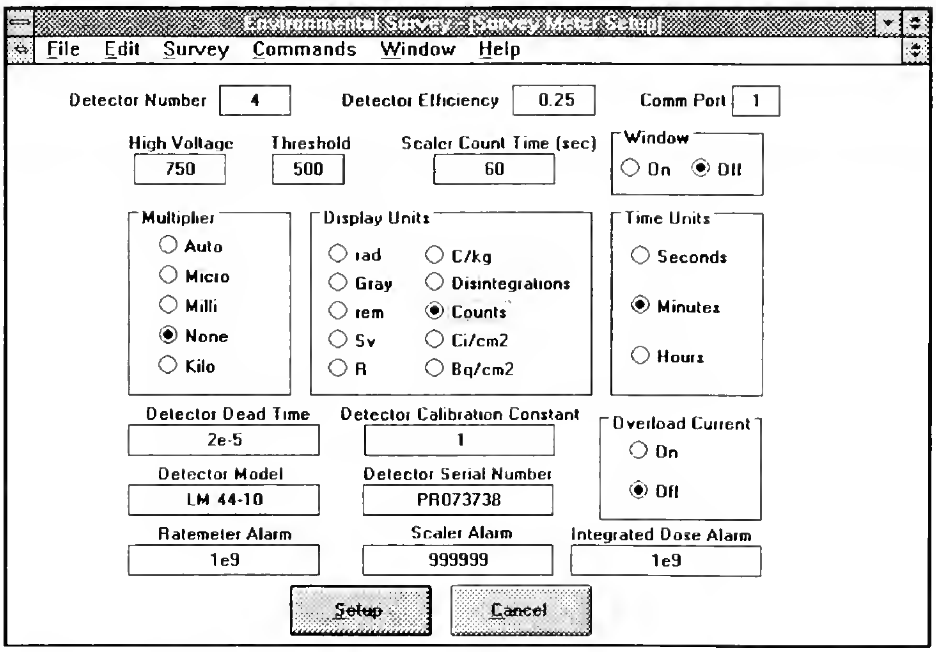


Figure 29. Instrument Configuration Screen.

The values for the dead time and the calibration constant are found by following a routine provided by the manufacturer. However, the efficiency of the detector is determined specifically by using calibrated sources of the radionuclides expected to be found during the survey. The configuration screen provides the user with the means for either manually entering the detector efficiency or by going through an efficiency resolution routine. The user can enter a subroutine that will calculate the detector efficiency as the mean of several counts (e.g., n=5 counts of 30 seconds). The procedures for determining the detector efficiency are detailed in the standard operating procedures found in Chapter 4 and the appendices.

Background counts screen

Once the configuration has been completed, the user can proceed on to the background counts screen. However, due to program limitations, the background counts can only be determined after the unit has been configured. Thus, the system provides the necessary controls to keep the operator from improperly sequencing through the survey procedures. Figure 30 illustrates the background counts screen.

The ORISE Survey Procedure Manual recommends that the surveyor take between eight and ten background readings (ORISE, 1993). Thus, the background counts screen provides a counter that automatically counts down from n = 9 samples. However, the number of background readings can be overridden by initially changing the number in the counter box. The screen also provides a box for count time input as well as a box that indicates the average background from the samples taken.

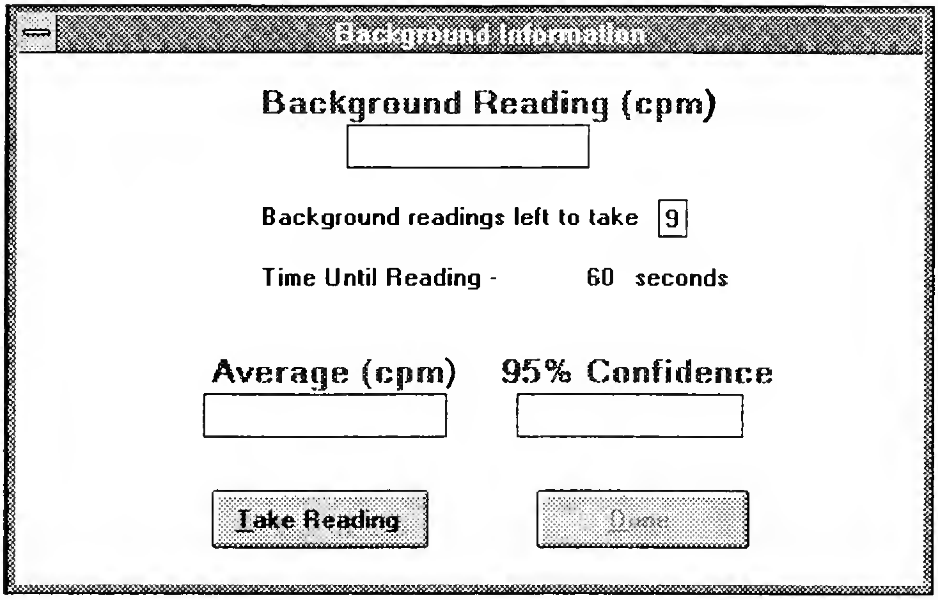


Figure 30. Background Screen.

Sampling with mouse-traversing positioning screen

After the average background counts for the survey are resolved, the user can proceed to a survey sampling screen, depending upon which automated survey technique will be utilized. For example, if the technician plans to use the mouse-traverse technique, he/she will enter this command from the menu. The form for sampling with mouse-traversing is shown in Figure 31.

The mouse-traverse technique utilizes a relative positioning technique much the same in principle as a computer mouse. Thus, depending on the movement of the trackball on the underneath side of the mouse assembly, a relative distance measurement in the forward/backward or side-to-side direction(s) can be determined. After initial calibration (i.e., algorithm development) and zeroing of the unit, the differential readings obtained are simply just differences in voltages.

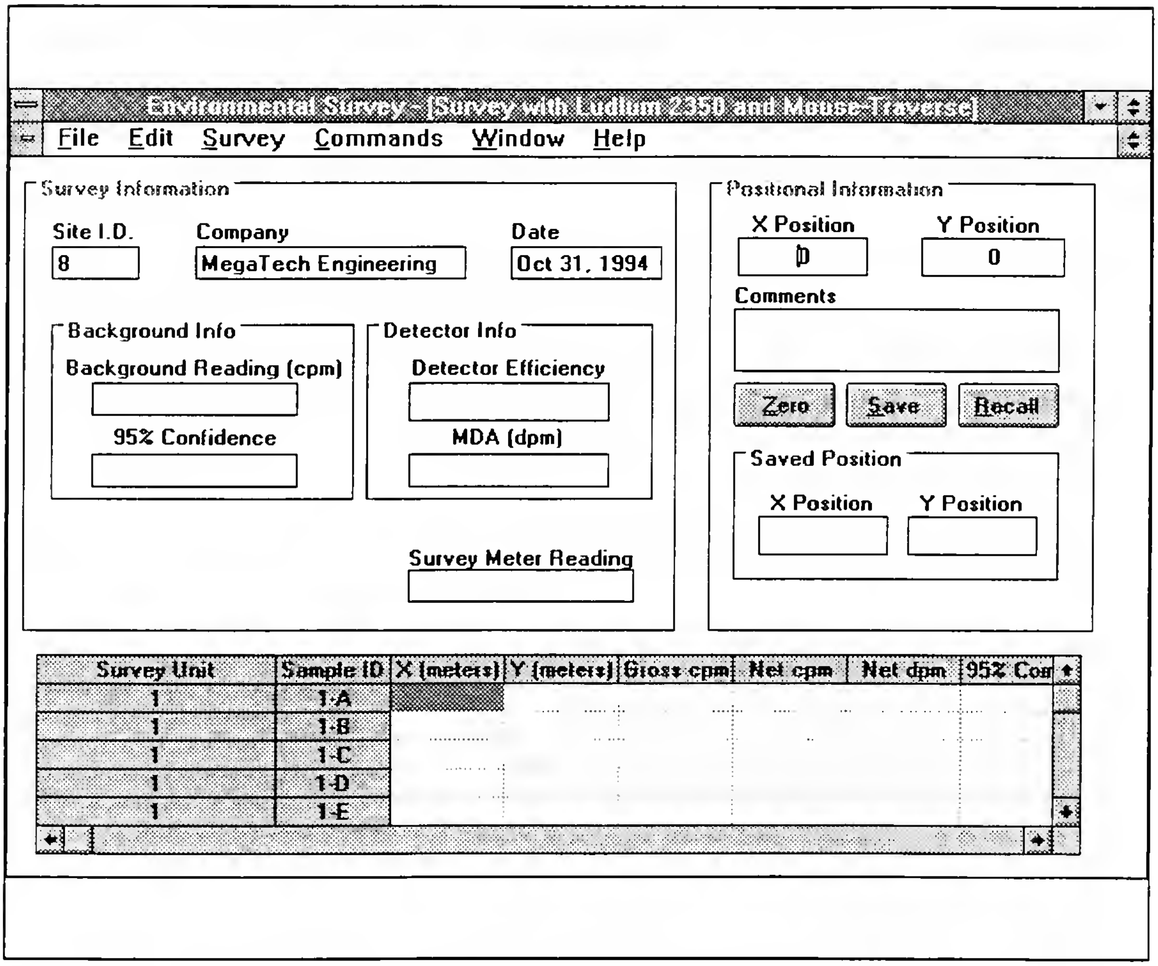


Figure 31. Sampling Screen with Mouse-Traverse Positioning.

The screen provides boxes for continuous display of the automatically collected X and Y positional data. Thus, the operator knows at all times where the survey apparatus is located and can take a reading according to the standard operating procedures for the survey. As Figure 31 illustrates, the screen includes boxes for the MDA, detector efficiency, background counts, sample counts, as well a spreadsheet for data logging. In addition, the data logging spreadsheet provides a box for sample identification/survey unit identification, X position, Y position, sample counts per minute per 100 cm^2, sample disintegrations per minute per 100 cm^2, survey unit average, and survey unit 95% confidence value.

Once the surveyor has taken both spatial and magnitude readings, the next step is to log the readings. The logged readings are displayed in the spreadsheet for positional and radiation levels. After enough samples are logged to be considered a complete survey unit (e.g., nine points), the spreadsheet also displays the unit average and 95% confidence level. If any time during the survey the user wants to analyze the data, a 3-D profile can be generated in Stanford Graphics. In addition, site-specific data are automatically dumped to Microsoft Access, a database.

Sampling with ultrasonic positioning screen

Another automatic sampling option involves the use of the ultrasonic positioning device. The form for this method is given in Figure 32. As is evident from analysis of Figure 31 and Figure 32, the screen and associated value boxes provided to the user are very similar. However, there is one major screen difference between the two automatic sampling techniques; the boxes provided for spatial data are different. While the mouse-

traverse screen has boxes for only X and Y values, the ultrasonic screen provides not only boxes for data values but also directional reference and total transect options.

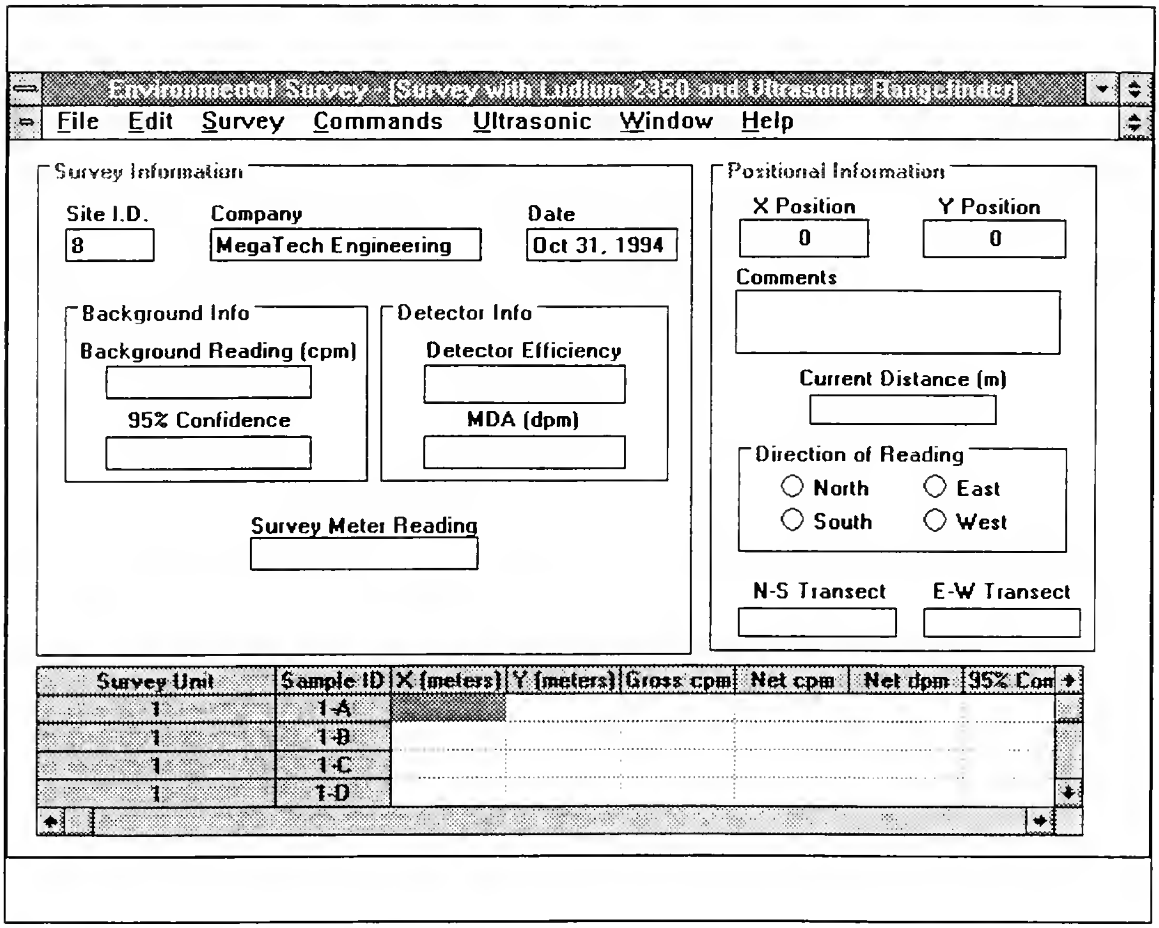


Figure 32. Sampling Screen with Ultrasonic Positioning.

When using the ultrasonic positioning device, the surveyor must set a zero reference and establish a starting point. In addition, it is necessary to begin the traverse with known room dimensions. Therefore, the screen provides data boxes for the north-south transect and the east-west transect. The other options and boxes provided on the screen provide the user with a means of ranging from any of the four room walls or from a fixed object.

As with the mouse-traverse sampling screen, this screen requires the user to log the data after taking the readings. In addition, the data can be analyzed anytime with Stanford Graphics and will be dumped to the database for further manipulation.

Positioning components and assemblies

Figure 17 and Figure 18 show close-ups of the positioning components and the mounting assembly. Both positioning transducers, the ultrasonic Piezo transducer and the mouse/trackball, are mounted to a directional adjustable lever which is connected to the survey apparatus. This lever can be accurately turned in increments of 90 degrees in either direction around its axis. This allows for the proper directional adjustments that must be made for both transducers. The techniques for making these adjustments are further detailed in the Chapter 4 and in the appendices.

The ultrasonic device came equipped with a digital circuit board that required a 12 VDC power supply. During operational check-out and calibration, it became apparent that the circuit board would be affected by the electromagnetic radiation given off by the notebook computer. This was evident in the noise observed and the erroneous positional

data acquired. Thus, a shielded box, also shown in Figure 17 as well as in Figure 18, was modified to hold and shield the circuit board.

Also, since the notebook computer only had one serial port, the system required the use of a multiplexing device to switch from one device to another. For example, both the Ludlum Model 2350 and the mouse required connection through the serial port. Thus, it was essential that the switching device be used while the mouse-traverse method was employed. The final component of the final prototype was a laser pointer. The pointer was only used as a means for providing a measurement quality control check. The pointer would be placed next to the ultrasonic transducer and activated toward the ranging surface.

CHAPTER 4
CALIBRATIONS, STANDARD OPERATING PROCEDURES (SOPs), AND QUALITY ASSURANCE

The purpose of this chapter is to provide a standardized set of indoor site survey procedures that are written such that they could be applied to both USDOE and NRC operations. In addition, quality assurance and quality control functions and procedures are detailed to help assure that the developed data from the automated indoor survey have both validity and quality.

While the procedures that are presented have been developed for a totally new automated technique for performing indoor site surveys, every effort has been made to emulate the currently accepted SOPs and quality assurance methods employed by the Environmental Survey and Site Assessment Program (ESSAP). However, due to the inherent differences between automated and manual methodologies, certain modifications were an imperative.

The procedures presented here are limited to those associated with automated indoor gamma, alpha, and beta radiological surveys. The instrument calibration and operational check-out procedures are detailed in Appendix C while the SOPs for the general and specific system surveys are given in Appendix D. However, the quality assurance/quality control guidelines are elucidated in this chapter..

This chapter will be used to summarize the main components from Appendix C

and Appendix D as well as outline the quality assurance and quality control measures taken to protect the site workers and to assure quality data collection. The chapter structure will begin with an overview of the instrumentation calibration and operational check-out for all the survey equipment and automated positioning equipment utilized at the site. Next, the SOPs for the automated site survey will be elucidated. And finally, the techniques employed to assure process quality will be detailed.

Instrument Calibration and Operational Check-Out

General Information

It is necessary to present a section with the objective of describing the general approach and operational check-out of all system components. In addition, survey responsibilities of personnel should be delineated.

The site coordinator is responsible for the implementation of the component calibrations and check-outs. However, all site survey personnel involved in the survey process are responsible for following all of the specific calibrations and operational check-outs. A site quality assurance officer should provide audits on these procedural activities.

All calibrations must be performed with standards traceable to the National Institute of Standards and Technologies (NIST) or other industry recognized standards organizations. The radiological instruments must be source-calibrated prior to each specific site survey to determine the necessary correction factors (e.g., detector efficiency, dead time, etc..). The devices used for automated positioning should be calibrated prior to each specific site survey with NIST traceable standards.

It is necessary to perform operational check-outs on all system components prior to each specific survey, and all of the components must be utilized in the same fashion as they were used during the calibration/check-out procedure. When possible, manufacturer specifications can be used to base threshold values upon.

The system equipment required to be operationally checked-out prior to the survey is given in Appendix C under Subpart B. A daily operational check-out of the radiological survey detector/ratemeter is required as a quality control measure. In addition, the operational check-out of the positioning devices is required prior to system use. The major concerns should be many connection and interfaces that are a part of the automated system as well as the power source levels.

Calibration of the Ludlum 2350 Ratemeter/Datalogger

The main objective of the calibration of the of the Ludlum 2350 Ratemeter / Datalogger (or comparable unit) is to assure that the error factors associated with unit circuitry will be minimized. This unit's calibration is the responsibility of the site coordinator while all survey personnel are responsible for following the calibration procedure. A list of the equipment is given under Section III of the calibration procedure for the Ludlum 2350 found in Appendix C. While most of the details required to calibrate the instrument are given in the appendix, it would be a good idea to use this calibration procedure while referring to the Ludlum Model 2350 Operations Manual.

It is necessary to operationally check-out the unit prior to the calibration. The

batteries need to be checked and replaced if the voltage is below 4.5VDC. If battery replacement is required, a "cold start" must be performed. For details on how to perform the "cold start", see Appendix C under the Ludlum calibration procedure or the Ludlum 2350 Operations Manual.

If the computer keyboard is not used to enter commands and data during the calibration, the hand-held terminal will need to be configured. However, the manufacturer-supplied software can be loaded and then the commands can be entered from the computer keyboard. The scheme used to configure the terminal is given in the appendix, however, the Ludlum Model 2350 Operations Manual can also be consulted.

It is necessary to both calibrate the unit for both unit dead time and calibration constant determination. The procedure to follow for both of these routines can be run by using the configured hand-held terminal or the computer keyboard (if the software is installed). The procedures for both of these calibrations are detailed in under Subpart C and Subpart D in Appendix C for the calibration of the Ludlum 2350.

Calibration and Operational Check-Out of a Gamma Scintillation Detector

The procedure for the calibration and operational check-out of the gamma detector was written specifically for those detectors that would could be coupled to the Ludlum Model 2350 ratemeter/datalogger. The site coordinator is responsible for the procedural implementation while the survey technician(s) is responsible for following procedural guidelines.

The preferred detector would be a 2X2 NaI detector such as the Ludlum Model

44-10 High Energy Gamma Detector. This detector is easily coupled to the Model 2350 with a manufacturer-supplied cable. Connections should be assured and the ratemeter batteries should be checked for a minimum voltage level of 4.5VDC.

The necessary commands found in Appendix C or in the Ludlum 2350 Operations Manual can be entered either from the configured hand-held terminal or the computer keyboard. An approximate value for the calibration high voltage level should be around 900 volts. A statistically sound number of background samples to be taken is 8-10 with a minimum count time of 30 seconds. The Environmental Survey software provides the user with the ability to do the calibration automatically. However, the user can opt to perform the calibration manually. The automatic method is elucidated in Appendix D in the Survey Standard Operating Procedures.

An Instrument Operational Checkout Form (See Figure C-1 in Appendix C) can be used to record the average count rate. However, the user can choose to save the data in the computer database instead. Determination of the acceptable background response limits must be made.

The gamma check source chosen for calibration must be representative of the expected radioactive material contaminating the survey site. The check source should be placed within close proximity of the face of the detector and start a 30 second count. Repeat this procedure 4 additional times and average. The +/-10% variation of the check source count rate average should be determined and used as the source response limits.

Either a computer record or a hard copy of these data must accompany the survey team to the survey site. In addition, the original check source must also accompany the

team to the survey site. If possible, a cross-calibration should be performed by using a pressurized ionization chamber (PIC). A calibration to the PIC is often used to convert from a point source efficiency to a plane source (e.g., floors, land, etc..) geometry. This will further increase instrument confidence in such geometries.

Calibration and Operational Check-Out of the Alpha Scintillation Detector

The objective of this calibration/operational check-out is to assure proper detector/instrument response and to determine appropriate correction factors. The site coordinator is responsible for the proper implementation of the procedure while the survey technician(s) is responsible for procedural adherence. The necessary equipment to perform the calibration and operational check-out are given under Subpart III under Calibration and Operational Check-Out of the Alpha Scintillation Detector in Appendix C.

The alpha detector chosen should be comparable to the Ludlum Model 43-89 Alpha/Beta Scintillator and should be securely connected to the Model 2350 with the manufacturer-supplied cable. After the battery voltage has been checked and the unit has been checked for pin-hole leaks as described, a threshold setting of approximately 50 mV should be entered. In order to determine the necessary high voltage value, a plateau curve must be constructed (See Figure C-2 in the appendix). The high voltage value will be selected as the midpoint of the plateau region on the curve and will be recorded or stored.

The background rate must be determined to set a baseline. The count time selected will be based on the specific alpha emitters that are expected to be found at the survey site. A sixty second count would be acceptable for all alpha emitters. However,

some radionuclides can be counted for thirty seconds per sample. The count times are primarily based upon acceptable surface levels. The technician should use the Ludlum Model 2350 Operations Manual to become familiar with the different commands if the calibration is being performed without the aid of the Environmental Survey software.

Whether the calibration is being performed automatically or manually, the procedure should include the taking of 8-10 background readings and determining a mean. After subtracting the mean background rate from the source counts, a response efficiency must be determined. This value should be between 15-30%, depending upon the radionuclide of concern.

The detector's minimum detectable activity (MDA) should be determined as outlined in the appendix. No survey sample values should be reported lower than the MDA value. Thus, it is likely that each survey unit's average will be biased on the high side. The MDA will be compared to the site guideline value and should be less than 50% of the applicable criteria for the site.

After the background is determined, the alpha detector should be used to perform 8-10, sixty second counts of the alpha check source. As with the gamma check source, the alpha source should be of the radionuclide type that is expected to be contaminating the site. A 3-sigma value and a mean should be established and saved or recorded. The same check source must be taken to the site for on-site calibration checks.

Daily instrumental operational check-outs should be performed as outlined in Appendix D. Hard copy forms can be used or the values can be stored in the computer database.

Calibration and Operational Check-Out of a GM Detector

The objective of this procedure is assure that the GM detectors that will be used to determine beta activity levels at site surveys are not only operable but that also proper correction factors are identified. The procedure is specifically written for those detectors that can be coupled to the Ludlum Model 2350 ratemeter/datalogger. As with other calibrations and operational check-outs, the procedural implementation is the responsibility of the site coordinator. The survey team or survey technicians have the responsibility of following the procedure.

The equipment necessary to perform the calibration includes primarily the detector, the Ludlum Model 2350, and the calibration/check sources. The calibration sources should be of the radionuclide type that will most likely be found at the survey site. In addition, this check source must accompany the survey team to the survey site for on-site calibration/check-out.

The calibration procedure calls for a threshold setting of 50 and a high voltage reading of 900 volts. These values will vary slightly, depending upon the beta contaminant of concern. A one minute background count should be recorded and repeated until a total of 8-10 readings have been attained. The background count mean and 3-sigma value should be calculated from these results.

Using a calibrated beta source and a one minute count time, a minimum sample of five repeat measurements should be taken. To increase statistical confidence, 8-10 repeat measurements could be taken. As was done for the background counts, a mean and a 3-

sigma value should be calculated. From this and the background data, the net counts, the efficiency, and the MDA are determined as outlined in the procedure.

A comparison of the calculated MDA to the site criterion is required. The MDA should be less than 50% the criterion value. If it is, then the detector can be assumed to be adequately sensitive enough for field use. All values found should be recorded on a manual form or saved in a database.

Repeat the counting process with the beta check source. The counts should be accumulated for one minute and should be repeated ten times. The mean and 3-sigma values are then determined. The field reliability of the detector is then determined by comparing the spread of the ten values about the mean. If the 3-sigma value is within 10% the mean value, then the detector can be deemed reliable enough for field use. As always, the data must be stored or recorded on an operational check-out/calibration form.

Daily instrumental check-outs and calibrations should be performed as outlined in Appendix D. Manual forms can be used or the data from all of the observations can be saved in a database for later hard copy generation.

Calibration of the Field Measuring Tape

The objective of providing this procedure is to assure that the positioning devices are accurately representing the spatial component of the survey. The field tape is primarily used for quality control checks, especially at control sampling points along the traverse. The standard calibrated field tape will also be utilized at the survey site as a means of calibrating the automated positioning devices.

The responsibility of assuring procedural implementation and for maintaining custody of the standard calibration tape is that of the site coordinator or the survey team leader. However, the survey technicians are responsible for following the outlines of this procedure. The main equipment needed to perform the calibration is the INVAR standard measuring tape (NIST traceable), the field survey tape, and an appropriate anchor.

In essence, the procedure involves anchoring the INVAR standard and the tape to be calibrated at the same point and running them adjacent to each other. With the two tapes anchored and stretched out parallel to each other, distance intervals of 1%, 5%, 10%, 25%, 50%, 75%, and 100% of the full tape length are taken. Typical tape lengths are either 30 feet or 10 meters. The values are manually recorded or entered into the computer database for comparison.

The field survey tape results and the INVAR measurements must comply to a +/- 1% criterion (i.e., all the field tape measurements must be within +/-1% of the INVAR measurements). If the points do meet this criterion, the field tape is considered to be calibrated and the INVAR standard can be cleaned and stored. The field survey tape must accompany the survey team to the survey site for automated positioning calibration and quality assurance.

<u>Operational Check-Out and Calibration of the Serial Mouse</u>

The objective of this procedure is to assure that the serial mouse or trackball used in the mouse-traverse positioning technique is operable and providing accurate spatial results. The site coordinator is responsible for the procedural implementation while the

survey technicians are responsible for the actual check-out and calibration. The main equipment necessary to perform this procedure is the calibrated field tape, the serial mouse assembly, a computer with serial port, and marking tape or pen.

Due to the mechanical nature of the serial mouse assembly, it is imperative that it be operationally checked-out prior to the calibration. The roller ball should be cleaned and the contacts should be adjusted and cleaned. After this initial maintenance, the mouse should be connected to the serial port of the computer and configured as specified.

A Serial Mouse Counts program was specifically written in Visual Basic to calibrate the four directions of motion. The program supplies the number of binary counts generated by the relative movement of the serial mouse and can be used for the calibration curve generation. The procedure involves the establishment of a reference point at one of the four corners of the mouse.

The mouse is then moved along a flat surface, with directional changes made only at 90 degree angles. At distances of six, twelve, and eighteen inches, the readings from the computer program are evaluated and recorded. The process was repeated for all of the four mutually orthogonal directions. Figure 33 illustrates the mouse calibration curve for the +X-direction.

The following equations were determined and replicated from the calibration curves that were generated and extrapolated from thes data:

+X-direction	$y = 0.003x - 0.0754$
-X-direction	$y = 0.003x + 0.0187$
+Y-direction	$y = 0.003x - 0.0299$
-Y-direction	$y = 0.003x - 0.2446$

where y = the distance in inches
x = the counts transmitted by the mouse

The above four calibration equations were then entered as algorithms in the main Environmental Survey software protocol.

The calibration curves and subsequent calibration equations should vary from mouse to mouse. Thus, a new set of equations will need to be determined each time the serial mouse is changed. In addition, the new coefficients will need to be entered into the protocol.

Operational Check-Out and Calibration of the Ultrasonic Rangefinder

The objective of this procedure is to provide a scheme for operationally checking-out and calibrating the ultrasonic positioning system. The procedure is specifically written for the Polaroid Ultrasonic Ranging Developer's Kit. Thus, the kit's operation manual should be referred to for clarification on any procedural activities. As for the serial mouse positioning assembly, the site coordinator is responsible for the procedural implementation while the survey team is responsible for following the procedural guidelines.

The primary equipment necessary for this operational check-out and calibration includes the Polaroid Ultrasonic Ranging Developer's Kit, a PCMCIA data acquisition card, a notebook computer, a shielded circuit board assembly, and the standard field calibration tape. All other equipment can be found in Subpart III under Operational Check-Out and Calibration of the Ultrasonic Rangefinder (Appendix C).

The operational check-out of the unit should begin by placing the kit's circuit board in the shielded box. If this is not done, the electromagnetic radiation from the notebook computer will cause erroneous results. The proper connections should be made and the power supply should be set at 12VDC (as outlined in this section in Appendix C).

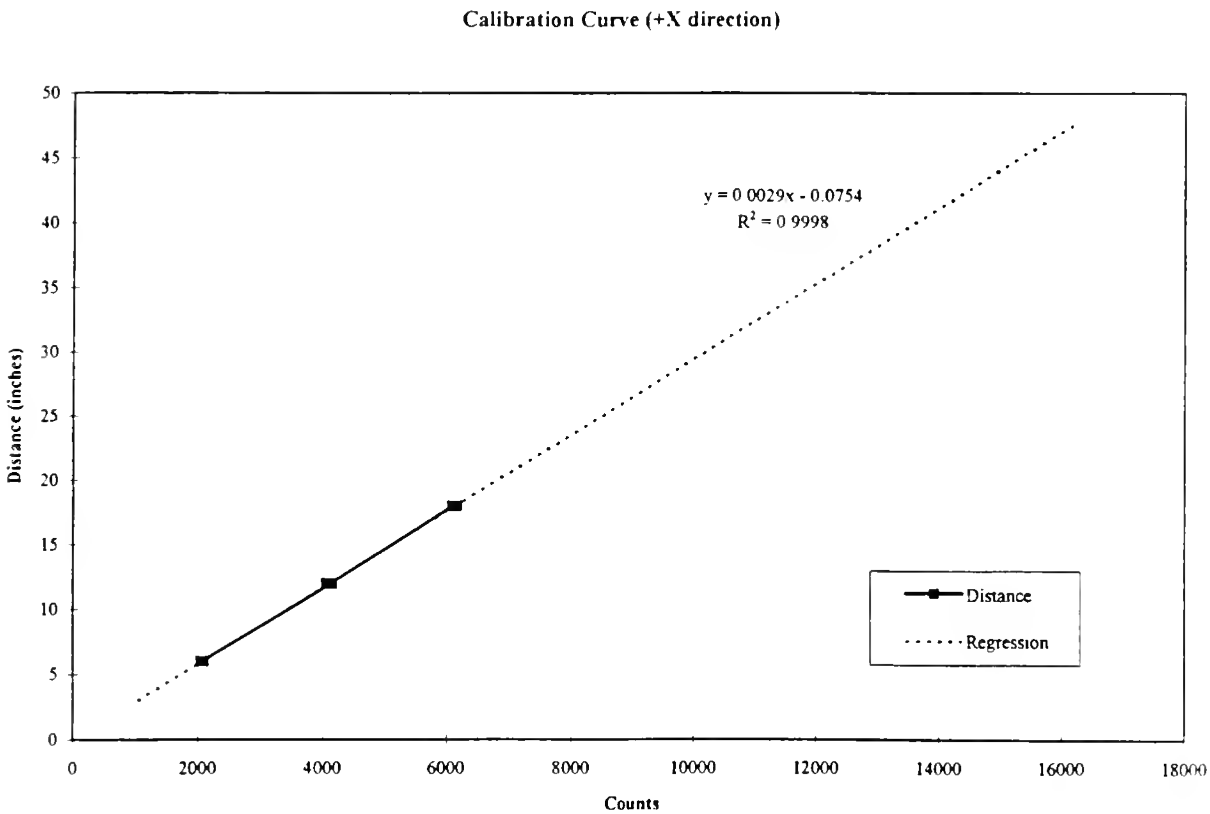


Figure 33. Calibration curve generated for +X-direction for mouse-traverse technique.

While the kit comes complete with three transducers, the best results have been attained with the Piezo transducer. Thus, this transducer should be connected as outlined in the procedures, and switch 2 (S2) on the circuit board should be placed in the 'Up' position.

Interfacing of the ultrasonic rangefinder to the notebook computer is through an electrical block and the configured PCMCIA data acquisition card. All of the previous connections should be performed without power to any of the components. After all the connections have been made, the power to the computer and circuit board can be turned on. The operation of the kit's circuit board can be easily resolved by visually inspecting the LED indicator on the board. If the board "lights up" and begins almost instantaneously making distance measurements, then the board is working properly.

It is important to check the system configuration and interfaces by selecting from the Windows Menu the NI-DAQ 4.5.1 program icon and running the Visual Basic AIAO program. The unit can be tested by executing several "voltage reads" while moving the Piezo transducer incrementally. It can be assumed that the unit is configured properly if the voltages change as the transducer is moved.

The actual rangefinder calibration can be performed from within this NI-DAQ 4.5.1 program or from within the Environmental Survey software program. If the user chooses to perform the calibration from within the Environmental Survey program, the user needs to identify a site, choose ultrasonic as the method of positioning, and then by-pass the configuration and background screens. The calibration is performed while on the main survey screen.

There is both a general rangefinder calibration procedure and an electronic

rangefinder calibration procedure. The former calibration is required for each site survey while the latter involves a "fine tuning" and should be performed periodically as needed.

The general procedure requires the determination of a maximum range of calibration. For indoor surveys, it is recommended that this maximum range be ten meters. The accuracy of the ultrasonic rangefinder is dramatically reduced after about ten meters because of signal attenuation and other systematic errors.

Initially, the standard calibration tape and the Piezo transducer must be located at a (0,0) reference point. The actual maximum measurement range, not to exceed 10 meters, is measured with the standard tape. Assuming that the calibration is being performed within the Environmental Survey software program, this distance is recorded in the computer screen box marked "North-South Traverse". It could have also been recorded in the "East-West traverse" box. The calibration continues by moving parallel to the tape, with the ultrasonic transmitting to the surface of concern (e.g., north wall).

Readings should be taken and logged at 5% intervals along the length of the tape. Thus, if the maximum range is 10 meters, the readings would be taken at 0.50 meter increments. A comparison of the ultrasonic readings with the readings located on the standard should be made. All of the points should satisfy a +/- 0.5% accuracy criterion. If the points don't meet this criterion, then the R22 gain control set point should be adjusted. After a slight adjustment of either in a clockwise or counter-clockwise fashion, the above calibration procedure should be repeated.

If the general calibration procedure does not provide the necessary accuracy guideline, it will be necessary to perform the electronic fine tuning procedure as outlined

in Appendix C under Operational Check-Out and Calibration of the Ultrasonic Rangefinder. The manufacturer will need to be called if there is no success in meeting the criterion after both calibrations are performed.

Automated Indoor Survey Standard Operating Procedures (SOPs)

General Site Survey SOPs

The main objective of this section is to provide the general procedures required for any type (i.e., alpha, beta, gamma) of automated indoor survey. However, specific operating procedures are given under another section for surveys of alpha, beta, or gamma contamination.

The site Standard Operating Procedures are detailed in Appendix D. This general section and the sections that will follow attempt to summarize some of the key points from each of the site SOPs found in the appendix.

For all site surveys, the responsibility for implementing the procedures is that of the site coordinator. On the other hand, procedural adherence is the responsibility of the survey technician(s). The equipment necessary for the automated indoor survey is given as Subpart III under General Site Survey Standard Operating Procedures in Appendix D. The equipment listed is the complete automated survey apparatus and accessories. The major components include the Ludlum Model 2350 ratemeter/datalogger, the notebook computer with the Environmental Survey program, the National Instruments PCMCIA data acquisition card, the appropriate detector, the automated positioning devices (i.e.,

serial mouse assembly and ultrasonic rangefinder) and the required calibration/quality control equipment.

The procedure begins with a preliminary survey site evaluation. This is the information gathering stage of the process. The room should be cleared of all obstacles as required, if possible. In addition, a room transect should be established with a quick subsequent manual or computer sketch. It is essential to determine the number of survey units that will be included in the room. A survey unit, as defined earlier, is approximately a one meter by one meter square sampling area. Due to the inherent physical limitations of the survey apparatus, the zero reference should be approximately 0.5 meters from adjacent, perpendicular walls. In addition, it is good practice to identify the corner of the room at which the zero reference will be established and stay with this convention throughout the progression of the site survey.

The next step is to set-up the total survey system. An on-site operational check-out of all system components is necessary as the components are being located on the survey apparatus. The mechanical distance counters on the survey wheels should be zeroed out and the calibrated check source should be used to determine the detector efficiency. The average of five sample counts of one minute each should be sufficient. The efficiency determined on-site for the specific detector should not vary by greater than +/-2% at one significant digit beyond the decimal point.

The next step is to enter the Environmental Survey program and complete the necessary preliminary configurations and inputs as outlined in Appendix D. From the background screen, 8-10 background readings should be taken and logged. These

readings should be taken from various locations near to the survey room (e.g., adjacent rooms, other building rooms, etc.). The software calculates all the necessary site parameters for the data entered on efficiency, configuration, and background. From this point, the specific standard operating procedures for alpha, beta, or gamma radiological surveys should be referred to for details on system set-up.

The general survey traverse techniques employed are given as Subpart C under General Site Survey Standard Operating Procedures in Appendix D. Most of the procedures are written in reference to floor surveys. However, the survey traverse techniques utilized for wall and ceiling surveys are discussed in sections where applicable. Due to the current software programming protocol, the locations of choice for reference zero is the southwest corner of the room at (0.50m, 0.50m) from the walls. This artificial zero reference is necessary because of the physical constraints posed by the survey apparatus.

The method of positioning chosen for the site is of major concern because it will determine the progression of the survey traverse from this point. If the ultrasonic method is chosen, then the north-south room transect and east-west room transect must be entered manually from calibrated field tape measurements. The necessary allowances have been entered into the program code to compensate for the artificial zero. However, it will be necessary to also identify the walls that the signal will transmit to and from. There is a box for this identification on the main program screen.

On the other hand, if the mouse-traverse positioning technique is used, then the (0,0) reference for the survey will be set at true (0.50m, 0.50m). In essence, the same

physical location will be utilized as that for the ultrasonic technique. The mouse-traverse will be zeroed at this point.

Independent of the positioning technique chosen, the survey proceeds by moving the total apparatus in a straight fashion from one end of the survey unit to the next. If the room has a tile floor, the lines made from where the tiles come together provide a good line of reference. Readings are taken and logged of both space and magnitude along the survey traverse of the survey unit. See Figure D-1 and Figure D-2 for the process sampling locations and traverse scheme (See Appendix D).

It was determined that a sample size of nine points per survey unit would give the survey a great deal of statistical confidence and validity. Current manual strategies require five samples per survey unit. However, the number of samples per unit was increased from the normal primarily due to the loss of sampling locations in the corners of the room. However, using this technique still provides six sample points per one meter by one meter area, even if the survey unit is defined from the true (0,0) of the room. The positioning assembly was machined such that the transducers could be turned 90 degrees with +/- 1% accuracy. It is necessary to always keep the mouse orientated in the direction of its original movement since it is a relative positioning technique. This is possible because the assembly/mechanism that it is attached to is designed to move at 90 degrees independently. Both Figure D-1 and Figure D-2 can be referred to for further clarification.

Figure D-2 illustrates the three different types of sampling locations; control, repeat, and survey. The control sampling locations are used as a spatial measurement

quality control measure. There is at least one control sampling point per survey unit. On the other hand, the repeat sampling locations are the means for meeting the 10% criterion required for repeat samples to be taken. This is a quality control feature aimed at checking the reliability and accuracy of the activity levels measured. The types of survey locations will be discussed in greater detail later in the sections on quality assurance and quality control.

It is usually necessary to survey the walls of the room up to two meters above the surface of the floor. In order to use the automated system, it will be necessary to remove the positioning assembly from the survey apparatus and "roll" it along the wall. If the ultrasonic positioning technique is utilized to take wall spatial measurements, it will be essential to take readings from the floor and ceiling, and thus, some minor program protocol changes must be made. The automated survey system as designed cannot survey ceiling or above ceiling locations. However, the Ludlum Model 2350, with coupled detector, can be detached from the rest of the unit and be used to take and store up to 256 locations at or above the ceiling level. These data can then be downloaded to the notebook computer. Details specific about each type of survey are given in Appendix D and summarized in the sections to follow.

Automated Indoor Alpha Survey Procedure

The main objective of this procedure is to describe an automated technique for determining the spatial and magnitude components at a site contaminated with alpha radiation on indoor building surfaces. The site coordinator is responsible for implementing

this procedure while the survey technician is responsible for procedural adherence. The equipment necessary for completing this procedure includes the total survey apparatus with a two-position serial multiplexer. In addition, an alpha radiation detector similar to the Ludlum Model 43-89 Alpha-Beta Scintillator and the calibrated alpha check source are necessary components.

The procedures outlined under the General Site Survey Standard Operating procedures for operational check-out and system set-up should be followed for the alpha survey traverse with ultrasonic positioning. The appropriate counting time is usually set at one minute for most alpha emitting radionuclides. This count time, along with other such parameters as efficiency, threshold, high voltages, scales, etc.., will be entered during the Ludlum configuration routine. The detector should be attached with the accompanying cable to the Ludlum Model 2350 and the instrument should be turned on to check for battery voltage. All other system operational check-outs should be performed as previously detailed in Appendix C.

The detector/ratemeter unit should be temporarily disconnected from the rest of the system to determine the efficiency of the detector on-site. The calibrated check source should be counted for five repeat measurements and the mean determined. This mean and the calibrated check source activity are then used to determine the efficiency. This value should coincide with the off-site efficiency within +/- 1%. If it does not, the process needs to be repeated. If the on-site efficiency still does not coincide with the off-site efficiency determination, then the Ludlum 2350 will need to be reconfigured with the weighted mean or arithematic mean, determined from the on-site and off-site efficiency, entered into the proper box on the configuration screen.

The survey traverse begins by positioning the total apparatus in the southwest corner of the room facing the north wall/surface. Perform the survey transect of the defined survey units by following the procedures outlined in the Survey Transect Procedure (General). The laser pointer should be placed next to the transducer and the light should be emitted to the surface of concern. This is a quality control check. The survey traverse should complete one survey unit before going on to another unit and measurements should be limited to a maximum of ten meters from transducer to target. Follow the instructions under Subpart IV in the procedures section of Automated Indoor Alpha Survey Procedures until the survey traverse has been completed.

A special effort needs to be made to keep the survey moving in a straight fashion and to make accurate 90 degree turns. The inability to control this aspect will lead to systematic errors that may need to be corrected for later. Quality control measurement analyses are to be performed on both spatial data (control points) and magnitude data (repeat points). The link has already been established between the Visual Basic and the Access database. A dynamic data link can also be quickly established between the database and Excel and Stanford graphics to provide a real-time 3-D representation of the room profile. All hard copies should be run and the necessary forms should be filled out as required in order to complete the survey.

If the mouse-traverse positioning technique is used, the survey traverse is completed in much the same fashion, with the exceptions being outlined previously other sections of Appendix C and Appendix D. It should be noted that the mouse-traverse

method is not recommended for use on floors other than tile or a similar flat material. Unlevel floors will lead to unacceptable spatial results. In addition, it should be emphasized that the serial mouse must share the computer serial port, through the 2-position multiplexer, with the Ludlum Model 2350. However, special messages and safeguards have been provided in the program to eliminate many potential problems this could pose.

Automated Indoor Gamma Survey Procedures

The purpose of this procedure is to describe an automated technique for performing gamma survey for indoor sites. Since the survey procedure is very similar to the automated indoor alpha survey procedure, the emphasis of this summary will be on the inherent differences between the two types of automated techniques. As for the alpha survey, the site coordinator is responsible for the procedural implementation while the survey technician is responsible for following the procedure.

The major components of the survey system are comparable to those already described in several previous sections. However, the major differences involve the type of detector used to detect gamma radiation and the type of mount required to meet specifications. A compatible gamma detector would be one like the Ludlum Model 44-10 High Energy Gamma Detector. This is a 2X2 NaI type scintillation detector. The mounting assembly must be attached to the survey apparatus at a location where the gamma detector can be mounted one meter from the floor. The readings taken and logged along the survey traverse will be from this one meter location. The current system has this

mounting assembly attached to its frame. The only other notable difference between the gamma survey and the alpha survey is the calibrated check source used to resolve the detector efficiency. The calibrated source needs to be one that is comparable to the site gamma emitting contaminant.

The Ludlum Model 2350 and detector should be operationally checked-out and the background rate should be estimated. In addition, the unit should be placed next to the check source and a count should be established. If the check source response is determined to be outside the established limits, then the unit should be removed from service.

The gamma detector should be disconnected from the Ludlum 2350 and placed inside the hole in the mounting assembly and adjusted to be one meter above the surface. This measurement should be made with the NIST traceable field tape. The detector is secured in place by the mounts three wing-nuts. The mount assembly will be used only for floor surveys. The detector must be manually positioned for the wall and ceiling surveys. The cable is then connected to the detector from the top of the mounting assembly and then connected to the Ludlum Model 2350.

The survey progression is now basically the same as for that of the automated alpha survey except for:

1. The units are set at micro-R/hour instead of counts per minute during the Ludlum configuration.

2. The sample reading should be taken and logged after about a five second stabilization period at each sample location. These readings are exposure readings and are estimated average rates for the regions of concern rather than an "absolute" reading obtained from a specified defined area.

The automated gamma survey can be successfully completed by abiding by the above exceptions and by following the survey traverse procedures as previously outlined (under the General Site Survey Standard Operating Procedures and the Automated Indoor Alpha Survey Procedures).

Automated Indoor Beta Survey Procedures

The objective of this procedure is to describe an automated means of performing an indoor beta survey. The beta survey traverse is basically performed in the same manner as the alpha and gamma survey traverses. However, there are a few notable exceptions.

The type of detector to be used must be one comparable to the Ludlum Model 43-89 Alpha/Beta Scintillator or a GM "Pancake type detector. The calibrated beta check source should be one that is comparable to the type of beta radioactive contaminant expected to be found on the survey site. In addition, an alpha shield, of approximately 5 micron thickness, may be required to allow for the differentiation between alpha disintegrations and beta disintegrations. Whether or not this shield is required depends on the detector used. The manufacturer's data sheet should provide this information.

The previous information on the indoor survey traverse should be followed, making the necessary changes specific to the measurement of beta radiation. The detector can be placed on the surface of the floor or wall or can be held at a couple of inches from the surface. If the beta detector is held a couple of inches from the surface, this will eliminate many of the alpha disintegrations that may be detected. See the Ludlum Model 2350 Operations Manual and the beta detector's manual for further clarifications.

Quality Assurance

Introduction

The quality assurance and quality control procedures in this section were developed for the new automated survey system and based upon criteria from:

1. Environmental Survey & Site Assessment Program (ESSAP)/ORISE.
2. DOE Order 5700.6C, Quality Assurance, August 21, 1991.
3. Quality Assurance Program Requirements for Nuclear Facilities, ASME NQA-1, 1989 Edition.

This section will not describe the administrative systems in great detail but instead will emphasize the specific quality control and quality assurance procedures for indoor site radiological surveys. The quality assurance and quality control procedures outlined in the following sections should be implemented in complement with all of the procedures in Appendix C and Appendix D.

Organization and Quality Assurance/Quality Control Duties

There should be a Program Director or Manager of Quality Assurance who would have the overall responsibility of the QA/QC activities. This individual's responsibilities should include data and training monitoring, audit initiations, report review, and procedure and policy establishment. An individual needs to serve as the Site Coordinator. For small operations, this individual can also serve as the site Health and Safety Officer. All survey team members are responsible for the quality of their own work. However, information

sources, in the form of Site Coordinators, QA Managers, or Health and Safety Officers, are required at each site for technical and quality questions that come up during the course of the survey. In addition, on larger projects involving many rooms to survey, additional personnel in the form of project leaders and senior health physics technicians are needed to perform training and to make some quality decisions.

Training and Certification

The following paragraphs outline the required training and certification for personnel performing radiological surveys. The training must be provided by currently certified individuals, and periodic updates are required of all certifications. Each specified certification and training must be updated within 365 days of the initial certification. However, a grace period of one month is considered acceptable.

The survey personnel must be given on-the-job-training from individuals certified in the area of concern (e.g., certified health physics technician instructing a junior health physics technician). All personnel who will be on-site are required by law to have the 40-hour OSHA Compliance course for hazardous waste site workers. In addition, they must be take the 8-hour refresher within one year of taking the 40-hour course. However, there is a one month grace period for taking the refresher. The 24-hour Hazardous Materials Technician Emergency Response Training course is also highly recommended for all survey personnel. In addition, all site personnel should be properly certified in CPR.

The Site Coordinator, Site Quality Assurance Manager, and/or Health and Safety Officer share in the responsibility that all of the survey site personnel have the minimum

training and certification requirements. Proper records on all personnel training should be kept in a database and hard copy form by the Health and Safety Officer.

All site training sessions should be designed to ensure that the individuals understand the purpose and the correct application of the procedures, the safety hazards associated, and the quality control requirements. All new and modified site procedures and must be explained clearly to all survey personnel. Proper documentation should be kept in hard copy form and in a database for all personnel training updates, re-certifications, and special training sessions attended.

Equipment and Instrumentation

All equipment and instrumentation to be used at an indoor radiological survey site should be uniquely identified and standards for calibration and operational check-outs should be established prior to any field use. The calibration of the field instruments used on the automated survey shall be based on standards traceable to the National Institute of Standards (NIST). Calibrations and operational check-outs of all survey equipment and instrumentation are given in Appendix C of this document. In addition, times for recalibration are given for each unit in Appendix C. In some cases (e.g., Ludlum Model 2350 Ratemeter/Datalogger), the instrumentation may be required to be sent back to the manufacturer for calibration. The documentation of all calibration and operational check-outs should be reviewed by the responsible quality assurance individual(s).

As the main means of procedural quality assurance, all components of the automated survey system are operationally checked-out and calibrated prior to each site

survey. Both an off-site calibration and an on-site calibration of the instrument detector are performed as a means of ensuring that minimal changes have occurred between the time that the detector was calibrated off-site and when it was calibrated on-site. These procedures are outlined in Appendix C and Appendix D. The responsibility of the calibration of all portable radiological survey instruments/detectors is the ultimate responsibility of the project leaders or site coordinators.

Quality Control

In order to provide an ongoing assessment of the equipment and the survey traverse procedure, quality control testing is essential for the activities that occur during the progression. Several different means of providing quality control for both data collection and procedural integrity are outlined in the paragraphs that follow.

The best means of explaining the quality control measures used to ensure spatial and magnitude integrity of the data is by referring to Figure 34. The survey units are defined as one meter by one meter areas. Nine samples are taken in each of these survey units. There are three types of sampling locations that have been defined; control sample points, repeat sample points, and regular survey sample points.

The control sample point is to provide the survey progression with some confidence that once a point is measured, that the unit can be returned to the point at some other time during the survey traverse within a certain level of accuracy. The survey technician identifies these control points by marking the location of the first reading. At a

convenient time during the survey traverse the technician then returns to this location and takes another positioning reading for comparison.

The repeat sample point is meant to provide a level of confidence and a means for controlling the quality of the data attained from the detector count. The detector is placed at the sampling location and a reading is taken and logged for that specific survey unit. The detector is then used to count for another minute and this value is a sample point for the adjacent survey unit. In the final analysis, a comparison of the two values taken from the same physical location is then made to provide a detector quality control check.

A minimum of 10% of the number of the samples in a survey unit should be repeated for statistical validity and equipment reliability/performance (ORISE, 1993). For the automated procedure, the number of samples either repeated for activity magnitudes or for spatial control is greater than this 10% criteria. Therefore, the quality control technique outlined for the survey traverse is within the established guidelines. In addition, depending on the type and the nature of the radiological survey assessment, it is acceptable to use either the sampled values or the 95% confidence values for the quality control comparison, however, the 95% values are preferred (ORISE, 1993)

Depending upon the relative percent difference (RPD) between the original sample point and the duplicate sample point, it may be necessary to throw out both pieces of data and re-sample. In cases where uncertainties are less than or equal to 10%, the RPD may be used to evaluate the results for acceptability. The RPD must be < 20 to be acceptable. The following equation determines the RPD:

$$RPD = \frac{(S - D)}{\left(\frac{S + D}{2}\right)} \times 100$$

where, S = Sample Result (either spatial value or activity level)
D = Duplicate Result (either spatial value or activity level)

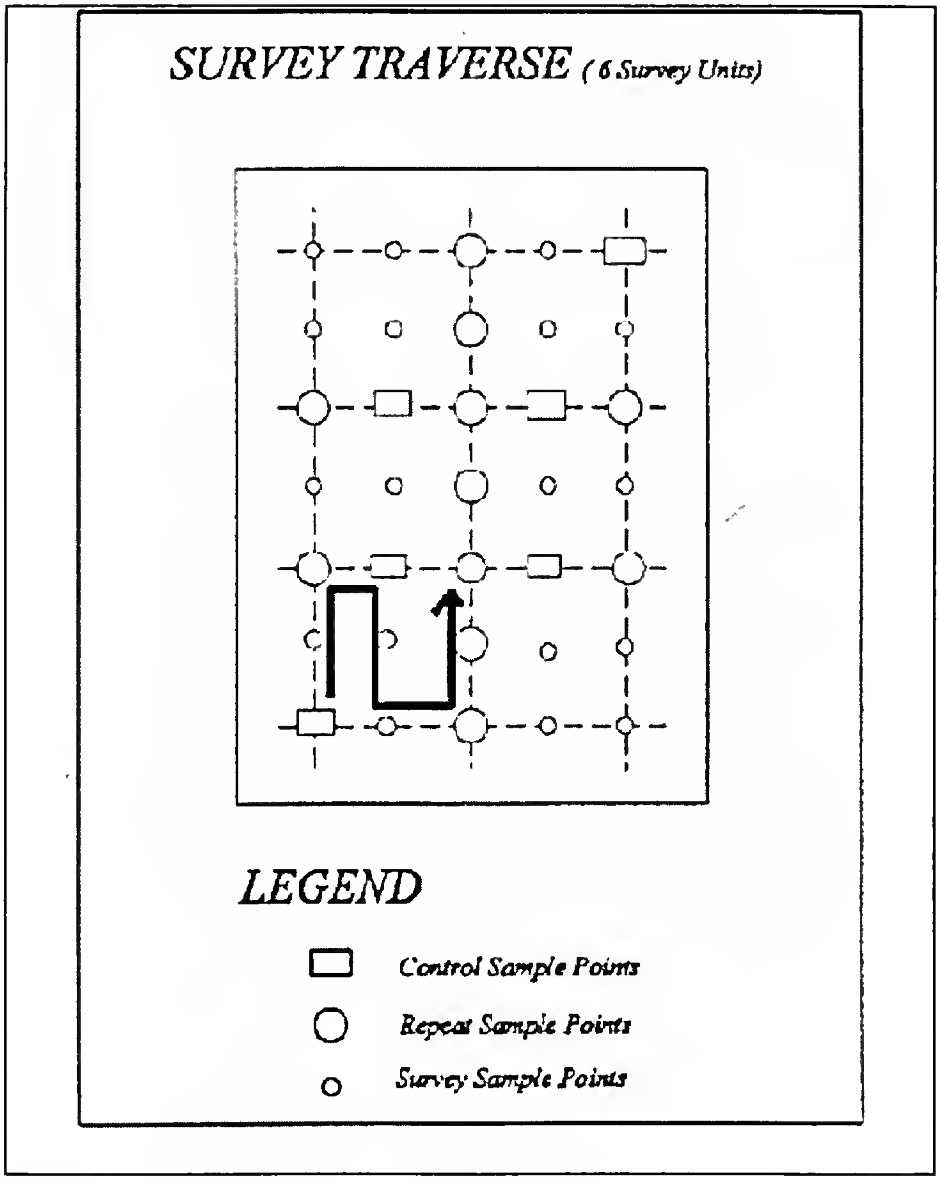


Figure 34. Automated survey sampling scheme.

By reviewing the illustration given in Figure 34, it can be seen that there are approximately 50% of the points that are repeated for activity measurements based on the one minute count times. In addition, the minimum number of control points per survey unit is one. However, most of the survey unit have two spatial control points. The initial sampling location and the final sampling location are also utilized as control sample points.

The control sample points have the additional attribute in that actual manual measurements using the NIST traceable field tape can be made from each of these points to the original sampling location. The values obtained by the automated positioning devices can then be compared to the actual values measured by the calibrated field tape. This provides another means of system quality control.

Two other system components that provide the procedure with controls for quality are the mechanical counters attached to the survey wheels and the laser pointer. The audible counters, with clicks at one meter increments, provide the user with a technique to quickly identify if the spatial readings taken by the automated device are providing erroneous results. The laser pointer is used to align up the ultrasonic signal with the surface it is transmitting toward. This eliminates the possibility that the reading being taken is, in actually, from some other undesirable surface.

Data Management, Review, and Validation

The automated indoor survey, as outlined in the procedures, will provide sufficient data for evaluation at the 95% confidence level for analytical results, and the proper algorithm was entered into the computer code for the automatic, real-time generation of

these values. In addition, the amount of data points allows for the detection sensitivities to be based on 2.71 plus 4.66 times the standard deviation of the background count (i.e., the minimum detectable activity). Due to these equations, a maximum of two significant digits should be reported. The data should be saved in both database form and on a hard copy in legible form.

The data should be reviewed for such attributes as recording/transcription, precision, consistency, and completeness. An assessment should be performed independently from the survey process to trace activities for defensibility and quality objectives. Computer processed or generated data from the system protocol should be checked by hand calculations of at least two sets of points for each parameter automatically calculated. Documentation should be kept on this quality control check of computer generated values. In addition, transcribed data shall be reviewed for accuracy by the supervisory technician. After these tasks are complete, the approval must be made for the release of the information. The approval should be made by the Manager of Quality Assurance for the project.

Assessments and Audits

A quality assurance officer should perform assessments on a continuous basis during the progression of the site survey. In addition, the officer, or another designated individual, should perform job-specific assessments. For example, the officer should assess areas and make determinations on whether or not the areas should be classified as affected or unaffected.

Quality audits must be conducted periodically (e.g., quarterly). In addition, quality audits of vendors may be necessary. Independent external quality audits may occur at any time by contracting organizations. At least one external audit per two-year period is recommended.

CHAPTER 5
SYSTEM FIELD IMPLEMENTATION

Introduction

After the system design, development, and operating procedures were completed, the next logical step was to pilot the technique at an indoor site with a high potential for radioactive contamination. The experimental design would include comparisons between the two automated positioning techniques and the current manual methods employed by survey technicians. It was determined that the ideal location would be one with several rooms of varying sizes. In addition, the site should be one where some initial survey data was available for evaluation for contaminant type and levels.

A site was located that met the above criteria. The location was an instrumentation building located on-site at a facility used for the processing of uranium-238. Arrangements were made to bring the equipment on location and to secure the services of two health physics survey technicians. The technicians were to provide technical expertise and to help with the manual surveys. The rooms in the building varied from very small (e.g., 3m X 3m) to surface areas of 400 meters-squared. Some of the rooms were tiled while others were carpeted.

Since the facility was used for the processing of uranium-238, the expected contaminants were alpha emitters from the U-238 decay chain (i.e., U-238, U-234, Th-

230, etc.). Previously, a gamma scan was performed to determine levels of contamination. While most of the rooms had some residual contamination, it was documented that the levels were low. Due to time constraints (i.e., outsiders were required to be escorted at all times), the preliminary survey planning included the decision to perform only alpha floor surveys and to limit the number of rooms to be surveyed. In addition, it was determined that the type of survey to be performed on-site would be only alpha characterization surveys, utilizing only the manual, ultrasonic (automated), and mouse-traverse (automated) techniques.

Specifically, the main objective of performing the surveys was to test the automated techniques for their viability in the field. In essence, it was necessary to follow the previously outlined procedures and quality assurance techniques to determine whether or not the automated system would provide a more effective and time efficient method of performing indoor surveys. Thus, in order to so, the experimental design needed to include statistical ways of comparing the automated survey system to the traditional, manual methods of performing the indoor survey. The purpose of the rest of this chapter is to elucidate the methods and procedures used during the evaluation, to present the data and results with statistically-sound comparisons, and to provide a discussion of the system performance and viability in the field.

Methods

Pre-survey planning included the review of available drawings of the rooms in the facility. It was determined that a good experimental design would be one that included

surveys from rooms of various sizes. However, since there were no large rooms in the building (i.e., >100 m^2), data from smaller rooms would have to be utilized for data extrapolation and experimental inference. Drawings indicated that most of the rooms at the location were rectangular. In addition, sources revealed that the rooms were all essentially free of equipment and obstructions.

The system equipment, detailed in Appendix D and in Chapter 4, was used to perform the surveys. The main components of the survey apparatus included a NEC 486 notebook computer with a configured National Instruments DAQ-700™ PCMCIA data acquisition card, a Ludlum Model 2350 Ratemeter/Datalogger™, a Ludlum Model 43-89 Alpha Scintillation Detector ™, and the two spatial positioning assemblies (i.e., ultrasonic positioning and mouse-traverse). The major system interfaces were shown in Figure 22 in Chapter 3.

Necessary computer protocol modifications were made based on site data and the techniques previously employed and outlined throughout the earlier chapters. While the normal process of performing indoor site surveys was to take five samples from each 1 m^2 survey unit, the system protocol was written to include nine sample points per survey unit. This would not only increase data confidence, but would also provide a more energy-efficient means of collecting the data. In addition, the nine points could help to serve as justification for requiring sampling in the difficult-to-reach corner and wall areas (i.e., only six points are taken in the one meter square area defined by one or more walls/surfaces).

The Environmental Survey software, written in Microsoft Visual Basic™, was developed to include a spreadsheet that identified spatial coordinates, cpm/100m^2,

dpm/100m^2, survey unit average, and a 95% confidence comparison value. In addition, the software included algorithms for determining detector efficiency, minimum detectable activity (MDA), the survey unit mean, the survey unit standard deviation, and the 95% confidence value. Code was written that would not allow a value of less than the calculated MDA to be logged. Computer forms (screens) that provided for survey background counts and detector/ratemeter configuration were also created. Since the Windows™ software environment was used, dynamic links between the various software packages made it possible to move data to and from various software programs (e.g., Visual Basic to Microsoft Access™, Access to Stanford Graphics™, etc..)

The algorithm entered for determining the MDA was as follows:

$$MDA = \frac{2.71 + (4.65\sqrt{B\,t})}{t\,E\,\frac{A}{100}}$$

where

MDA	=	activity level in disintegrations/minute/100 cm^2
B	=	background rate in counts per minute
t	=	counting time in minutes
E	=	detector efficiency in counts per disintegration
A	=	active probe area in cm^2

Since the counting time is usually set for one minute and the active probe area of the Model 43-89 detector is 100 cm^2, the MDA is primarily a function of the site background rate.

The equation used to determine the 95% confidence comparison value was as

follows:

$$95\%\ CCV = Xbar + 1.86 \frac{s}{\sqrt{n}}$$

where

95% *CCV*	=	95% confidence comparison value (positive side)
1.86	=	the t-value for sample size equal to 9
s	=	the standard deviation for the survey unit
n	=	the number of samples per survey unit

For this survey, the value for n is equal to nine and the calculations for the mean and standard deviation is depend upon the sample measurements for each survey unit. The standard statistical equations used to determine the sample mean and the sample standard deviation are included in the computer code to determine the appropriate 95% confidence comparison value.

Prior to leaving for the site, a calibration curve was generated by using a check source of Th-230. In order to determine the ideal high voltage value to use for the survey, an optimum threshold value was first decided upon. A good "rule-of-thumb" on determining the threshold is to use a value that, with several subsequent measurements, results in a background rate of not greater than 3 dpm. The threshold value that met this criterion for the thorium source was 30 mV. At this threshold, the calibration curve resulted in a plateau midpoint of 850 volts. This value was utilized as the survey high voltage and would be subsequently entered during the Ludlum 2350 configuration routine.

Upon arrival at the facility, it was resolved that alpha characterization surveys

were to be performed on floor areas of 6 m^2, 12 m^2, 25 m^2, and 42 m^2. Due to the security and time constraints at the facility, the manual method was performed on-site by the health physics technicians and observations were made for comparison. In addition, the mouse-traverse technique and the ultrasonic positioning method were both utilized to survey the 6 m^2 room. However, compatible "clean" rooms off-site were used to obtain data for the other three areas.

Operational check-out and calibration procedures outlined in Appendix C and in Chapter 4 were completed prior to beginning the first survey. A 522,000 dpm calibrated check source of Th-230 was used to determine the efficiency of the detector. The procedure included calculating the mean of five subsequent one minute counts from the detector and dividing it by the calibrated value. Then, by multiplying this resultant by 100, the survey detector efficiency was attained. This value was found to be 19.6%.

A survey background rate was determined both manually and automatically. Nine points were taken from adjacent, unaffected areas. The mean of these nine samples was then used to set a baseline for determining net sample counts. In addition, the background mean is an important parameter used in the calculation of the detector MDA. The time required to take the background readings first manually and then automatically was essentially the same.

After a detector efficiency was determined from a calibrated Th-230 check source, the two survey technicians proceeded with a calibrated field survey meter (with attached alpha detector) to perform a quick alpha scan of the rooms to determine potentially affected areas. The technicians then began to grid the rooms into survey units of

approximately one square meter. Figure 35 shows the survey grid for an approximately 3 meter by 4 meter room that was manually surveyed. The technicians used a calibrated field measuring tape and duct tape to grid the room. Five sample points were taken (i.e., the four corners and the midpoint) to define each survey unit. In addition, one sample location was repeated for every two survey units completed. This is in compliance with the 10% quality assurance criterion recommended for the detector. Since one of the primary contaminants was thorium-230, which has a rather stringent release criterion (i.e., 100 dpm/100 cm^2 average), the count time was one minute for each sample. One technician operated the instrument while the other manually documented the readings. The detector was moved around the sampling area in a sigmoidal fashion for the duration of the one minute sampling. The manual surveys were observed for time requirements and technique. After a survey was complete, the technicians calculated the required values.

After the background rate and detector efficiency was determined, each of the automated characterization surveys began with an initial tape measurement of room dimensions. The procedures for operational check-out, site calibration, and standard operating procedures, detailed in Appendix C, Appendix D, and Chapter 4 for alpha surveys, were followed. A special effort was made to determine values for repeatability (both spatial and magnitude) and spatial measurement error/accuracy. In order to do so, some of the sampling locations had to be specified as either control or repeat sampling locations. The control data points are defined as those points used as a means of showing spatial repeatability and accuracy. The control points were marked with a pencil or a piece of tape, and the surveyor returned to this location, during the course of the survey

traverse, to determine the level of positioning repeatability. In addition, these control points are compared by means of actual tape measurements for accuracy.

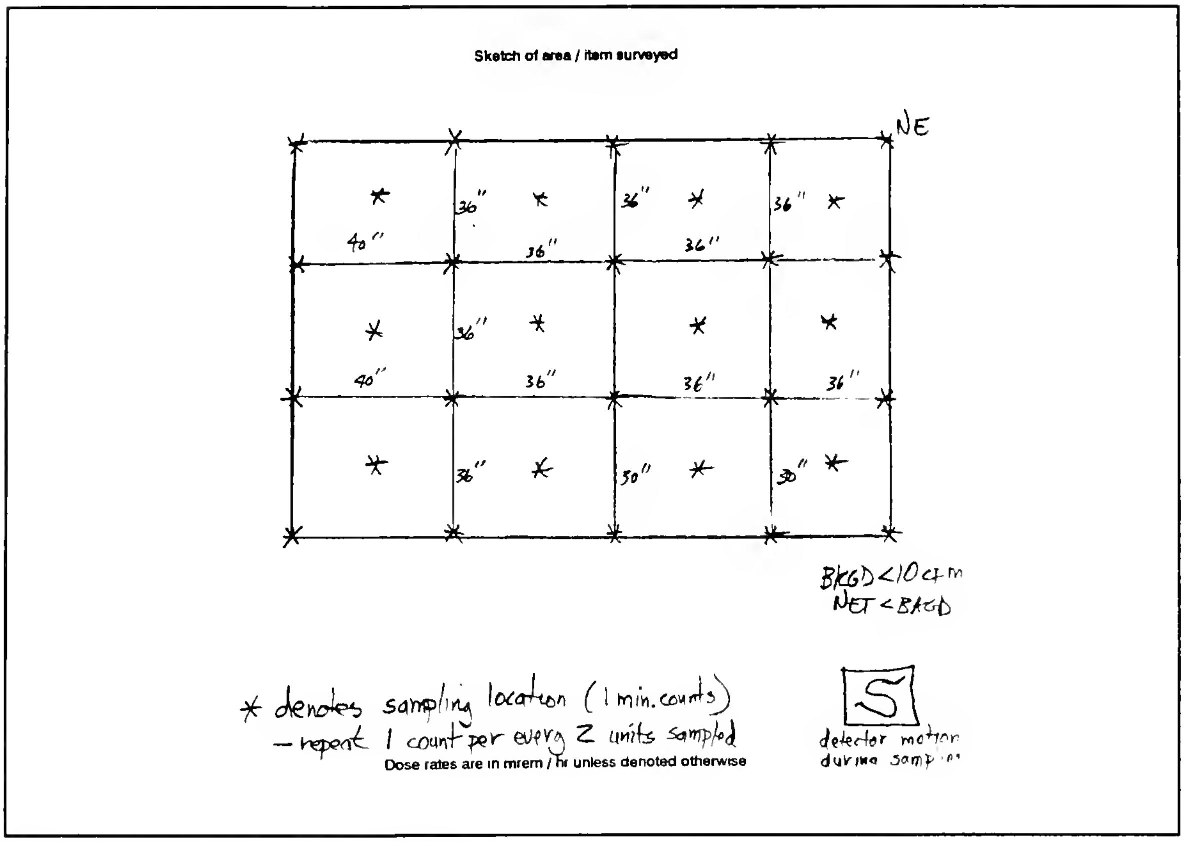


Figure 35. Manual field survey grid.

A repeat sample point is one in which the surveyor just repeats the count with the detector/ratemeter. Repeat points were necessary as a quality control measure, required to meet the 10 percent repeat point criterion recommended by ORISE. Repeat points were taken near the midpoint location on the survey lines of adjacent survey units.

Specifically, the experimental design followed for the automated techniques involved data gathering methodologies aimed at gaining insight on the actual process viability. As was hinted in the previous paragraph, spatial accuracy, temporal efficiency,

and measurement repeatability are critical indicators of process field viability.

In order to provide some indication of the viability of the automated positioning techniques for field use, values for spatial accuracy and repeatability for the three meter by four meter room were taken. The survey traverse for the 12 m^2 area (i.e., 3 meter by 4 meter room) is shown in Figure 36. Figure 36 defines the twelve survey units, with specific identification made of the sampling locations which were used as control points (CP) and repeat points (RP). In addition, Appendix D provides two drawings showing the automated survey traverse.

A viability and time efficiency comparison, between the traditional manual method and the two automated techniques, was performed. This was accomplished by defining a man-hour comparison coefficient, the dependent variable, and plotting it versus the room floor area, the independent variable. Thus, an equation can be determined from the data taken from the smaller rooms to help describe the time component for surveys of larger areas. The man-hour comparison coefficient, k, was defined as follows:

$$k = \frac{t_a}{t_m}$$

where

k	=	man-hour comparison coefficient
t_a	=	total man-hours for automated survey
t_m	=	total man-hours for manual survey

Also, a time comparison was made that paired the manual technique against both of the automated techniques. These comparisons were based on the standard statistical t-test, with temporal data obtained from a typical surveyed area and defined survey unit(s). In addition, to show the real-time data analysis capabilities of the system, a real-time profile of the spatial and magnitude components for a 2 meter by 3 meter room was generated on-site. The data were taken from the one minute alpha counts at each floor

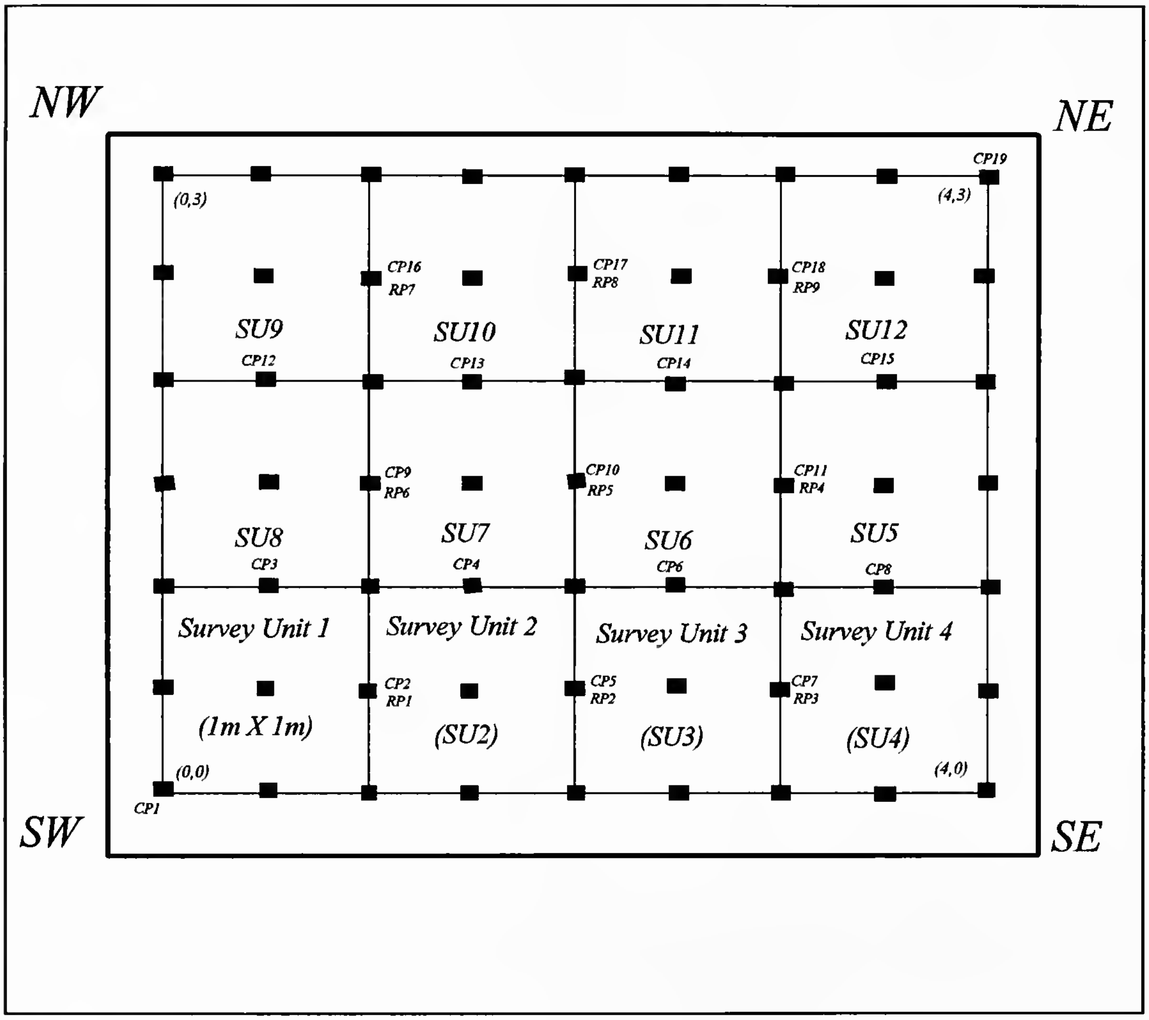


Figure 36. Four meter by three meter survey area.

location and plotted three-dimensionally by linking the database with Stanford Graphics™.

Finally, a total area assessment was made by determining the population mean and standard deviation for the 6 m^2 area. Detector measurement repeatability was determined by repeating the one minutes counts at one location in each survey unit. A relative percent difference calculation was made on these data and compared to the < 20% criterion for acceptance.

Results of Field Implementation Study

Spatial Accuracy and Spatial Repeatability

One main purpose of this research was to show that automated positioning could provide an effective and efficient means of replacing the time consuming efforts involved in the manual gridding of indoor survey sites. Calculations for spatial accuracy and spatial repeatability provide two objective measures for the evaluation.

Table 4 provides the spatial accuracy and repeatability data obtained from the 12 m^2 survey area while using the ultrasonic positioning technique. Table 5 provides the same data for the mouse-traverse technique. The nineteen control points, defined on the survey map shown in Figure 35, are the locations where the comparisons were made. The actual distance data were determined by measuring with a calibrated field measuring tape.

The mean accuracy for the ultrasonic positioning technique was 99.6% in the x-direction and 98.5% in the y-direction. The standard deviation was calculated to be 1.7% in the x-direction and 1.5% in the y-direction. Thus, at the 95% confidence level, the

accuracy for the ultrasonic positioning technique can be stated as 99.6% +/- 0.8% in the x-direction and 98.5% +/- 0.6% in the y-direction. The 95 % confidence levels for these and the following spatial parameters were calculated by using the following equation:

$$P_{95} = Xbar \; +/- \; 1.96 \frac{s}{\sqrt{n}}$$

where

P_{95}	=	the 95% confidence parameter desired
$Xbar$	=	the mean of the data
s	=	standard deviation
n	=	the number of samples

The mean calculated for the relative percent difference (RPD) between the control points was 0.3% in the x-direction and 0.1% in the y-direction. The standard deviation was found to be 0.5% in the x-direction and 0.5% in the y-direction. Thus, at the 95% confidence level, the RPD for the ultrasonic positioning technique can be given as 0.3% +/- 0.2% in the x-direction and 0.1% +/- 0.2% in the y-direction.

TABLE 4
ACCURACY AND REPEATABILITY OF ULTRASONIC POSITIONING

Control Pt. Location (x,y in meters)	Measured Ultrasonic (x,y in meters)	Error (x,y) (Absolute Value in meters)	% Accuracy (x,y)	Ultrasonic Return Measure (meters)	RPD (Ultrasonic Samples both x,y)
0.00, 0.00	0.00, 0.00	0.00, 0.00	N/A	0.01, 0.00	200%, 0%
1.00, 0.50	0.97, 0.49	0.03, 0.01	97.0, 98.0	0.98, 0.49	1.0, 0.0
0.50, 1.00	0.47, 0.98	0.03, 0.02	94.0, 98.0	0.47, 0.98	0.0, 0.0
1.50, 1.00	1.48, 0.98	0.02, 0.02	98.7, 98.0	1.53, 1.02	10.0, 0.0
2.00, 0.50	2.00, 0.47	0.00, 0.03	100, 94.0	2.00, 0.52	0.0, 3.3
2.50, 1.00	2.48, 0.98	0.02, 0.02	99.2, 98.0	2.48, 0.98	0.0, 0.0
3.00, 0.50	2.99, 0.48	0.01, 0.02	99.7, 96.0	2.99, 0.48	0.0, 0.0
3.50, 1.00	3.46, 0.98	0.04, 0.02	98.9, 98.0	3.47, 0.98	0.1, 0.0
1.00, 1.50	1.02, 1.48	0.02, 0.02	102.0, 98.7	1.02, 1.48	0.0, 0.0
2.00, 1.50	1.98, 1.50	0.02, 0.00	99.0, 100	1.98, 1.50	0.0, 0.0
3.00, 1.50	3.02, 1.48	0.02, 0.02	100.7, 98.7	3.01, 1.48	0.1, 0.0
0.50, 2.00	0.50, 1.99	0.00, 0.01	100, 99.5	0.49, 1.99	2.0, 0.0
1.50, 2.00	1.52, 1.97	0.02, 0.03	101.3, 98.5	1.52, 1.97	0.0, 0.0
2.50, 2.00	2.50, 2.00	0.00, 0.00	100, 100	2.50, 2.00	0.0, 0.0
3.50, 2.00	3.50, 1.98	0.00, 0.02	100, 99.0	3.49, 1.98	0.3, 0.0
1.00, 2.50	1.01, 2.48	0.01, 0.02	101.0, 99.2	1.01, 2.48	0.0, 0.0
2.00, 2.50	2.01, 2.48	0.01, 0.02	100.5, 99.2	2.01, 2.48	0.0, 0.0
3.00, 2.50	3.00, 2.47	0.00, 0.03	100, 98.8	2.99, 2.47	0.3, 0.0
4.00, 3.00	3.99, 3.01	0.01, 0.01	99.8, 99.7	3.99, 3.01	0.0, 0.0

TABLE 5
ACCURACY AND REPEATABILITY OF MOUSE-TRAVERSE POSITIONING

Control Pt. Location (x,y in meters)	Measured Mouse-Traverse (meters)	Error (x,y) (absolute value in meters)	% Accuracy (x,y)	Mouse-Traverse Return (meters)	RPD (original & return samples)
0.00,0.00	0.00, 0.00	0.00, 0.00	*N/A	-0.04, 0.05	**N/A
1.00, 0.50	0.96, 0.51	0.04, 0.01	96.0, 102.0	0.95, 0.54	1.0, 5.9
0.50, 1.00	0.51, 0.99	0.01, 0.01	102.0, 99.0	0.48, 0.95	5.9, 4.0
1.50, 1.00	1.44, 1.03	0.06, 0.03	96.0, 103.0	1.47, 1.00	2.1, 2.9
2.00, 0.50	1.94, 0.57	0.06, 0.07	97.0, 114.0	1.97, 0.56	1.5, 1.8
2.50, 1.00	2.44, 0.96	0.06, 0.04	97.6, 96.0	2.45, 0.95	0.4, 1.0
3.00, 0.50	2.86, 0.46	0.14, 0.04	95.3, 92.0	2.96, 0.51	3.5, 10.9
3.50, 1.00	3.47, 0.98	0.03, 0.02	99.2, 98.0	3.48, 0.96	0.3, 2.0
1.00, 1.50	1.05, 1.50	0.05, 0.00	105.0, 100	1.04, 1.51	1.0, 0.7
2.00, 1.50	2.00, 1.53	0.00, 0.03	100, 102.0	2.02, 1.50	1.0, 2.0
3.00, 1.50	3.01, 1.51	0.01, 0.01	100.3,100.3	2.96, 1.45	1.7, 4.0
0.50, 2.00	0.53, 2.03	0.03, 0.03	106.0,101.5	0.52, 2.00	1.9, 1.5
1.50, 2.00	1.51, 2.05	0.01, 0.05	100.7,102.5	1.52, 2.03	0.7, 1.0
2.50, 2.00	2.47, 2.03	0.03, 0.03	98.8, 101.5	2.46, 1.95	0.4, 3.9
3.50, 2.00	3.48, 1.99	0.02, 0.01	99.4, 99.5	3.45, 1.97	0.9, 1.0
1.00, 2.50	1.00, 2.54	0.00, 0.04	100, 101.6	0.98, 2.54	2.0, 0.0
2.00, 2.50	2.01, 2.50	0.01, 0.00	100.5, 100	2.04, 2.53	1.5, 1.2
3.00, 2.50	3.05, 2.48	0.05, 0.02	101.7, 99.2	2.95, 2.54	3.3, 2.4
4.00, 3.00	3.92, 3.02	0.08, 0.02	98.0, 100.7	3.96, 2.94	1.0, 2.6

* No accuracy value (mouse must be zeroed to traceable tape).
**Value is not used in RPD calculations.

For the mouse-traverse technique, the mean accuracy calculated for the x-direction at the 95% confidence level was 100.1% +/- 1.4% while the 95% confidence level mean in the y-direction was found to be 100.7% +/- 2.0%. The 95% confidence level RPD for the mouse-traverse technique in the x-direction was calculated to be 1.7% +/- 0.7%. The corresponding 95% level for the RPD in the y-direction was determined to be 2.7% +/- 1.2%.

The positioning parameters for both the ultrasonic positioning technique and the mouse-traverse technique are summarized in Table 6.

Table 6
Ultrasonic and Mouse-Traverse Positioning Statistics

TECHNIQUE	Accuracy % X-Direction (95% CL)	Accuracy % Y-Direction (95% CL)	RPD (%) X-Direction (95% CL)	RPD (%) Y-Direction (95% CL)
Ultrasonic Positioning	99.6% +/- 0.8%	98.5% +/- 0.6%	0.3% +/- 0.2%	0.1% +/- 0.2%
Mouse-Traverse	100.1% +/- 1.4%	100.7% +/- 2.0%	1.7% +/- 0.7%	2.7% +/- 1.2%

Survey Time Comparison

In order to provide some indication of the time efficiency of the automated techniques, a test was needed that would allow for comparison of temporal components of both automated survey techniques against the traditional, manual survey. In order to do so, it was necessary to define a man-hour comparison coefficient. In essence, this is just the man-hours required to perform an automated survey of a particular area divided by the time required to complete the survey with the manual technique.

Survey areas of 6 m^2, 12 m^2, 25 m^2, and 42 m^2 were chosen to perform controlled surveys, utilizing each of the three techniques (i.e., manual, ultrasonic, and mouse-traverse). The time component for each of the surveys was recorded, and the comparison coefficient was plotted as a function of survey area. An extrapolation was made and an equation was estimated that would help to describe the time efficiency of the automated techniques for very large rooms. Since the relative time component required for gridding and manual calculations would be greater with increasing survey area, it was expected that the plot would follow a negative exponential path.

Figure 37 and Figure 38 provide the data plots for the four areas and the extrapolation data for areas up to 100 m^2. Figure 37 uses a man-hour comparison coefficient derived from time data required to perform the automated ultrasonic survey and the manual survey. Figure 38 shows a plot of the data when the coefficient is determined by time allocations utilized to complete each respective mouse-traverse survey. Table 7 shows the man-hours associated with each of the four survey areas. The table also gives the man-hours comparison coefficient (MHCC) in parentheses.

For the manual surveys, the major temporal components are the time to grid, the detector count time, and the time to perform the calculations. Since the necessary calculations and the gridding are performed automatically, the only major time components for the automated methods are the survey sampling times and the QC/QA checks. In addition, for the manual method, the relative amount of time spent on gridding and performing calculations increases as the size of the survey area increases. Thus,

theoretically, as the time component for manually surveying a room gets increasingly weighted by gridding and calculating, it is expected that the comparison coefficient would diminish to zero. However, by extrapolating the data plots, it appears that both curves are actually approaching approximately 0.4. This would indicate that there is a finite limit to the time savings that could be attained by the automated techniques, and that other inherent system variables seem to be limiting the system efficiency. Conclusively, the data indicate that the automated processes will allow nearly twice the sampling points in forty percent of the amount of time.

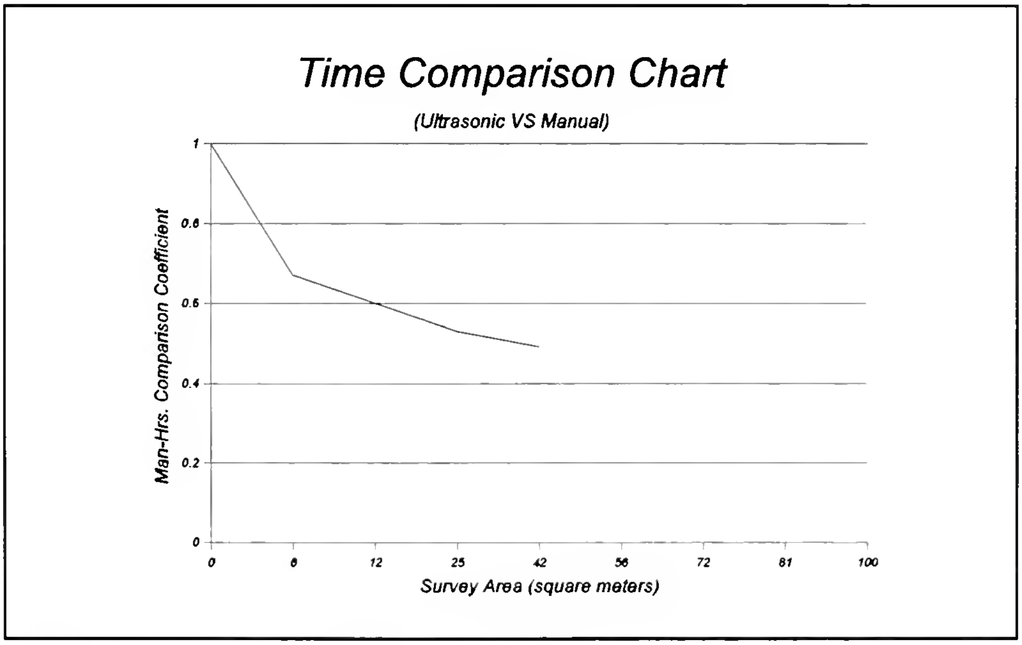


Figure 37. Time comparison graph for ultrasonic versus manual survey.

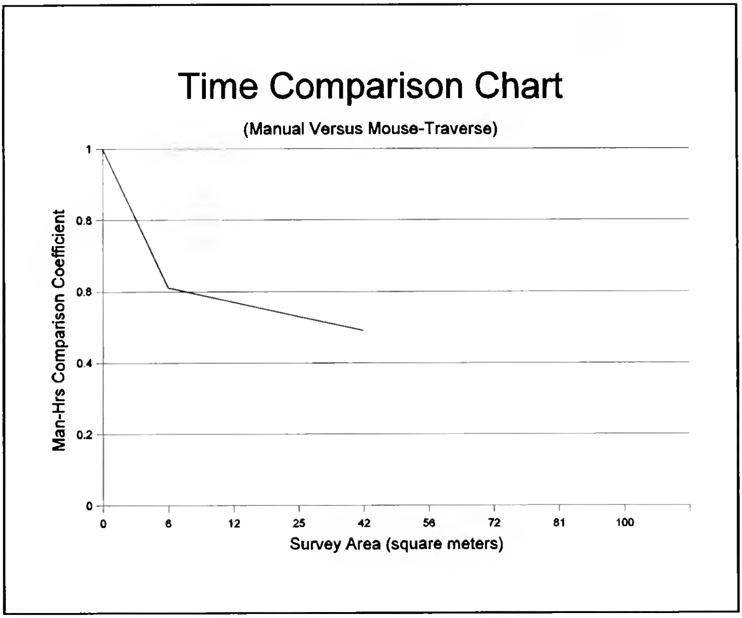


Figure. 38. Time comparison graph for mouse-traverse vs. manual survey.

TABLE 7
CHARACTERIZATION SURVEY COMPLETION TIME

TECHNIQUE	Man-Hrs $6m^2$ Area	Man-Hrs $12m^2$ Area	Man-Hrs $25m^2$ Area	Man-Hrs $42m^2$ Area
Manual Survey	2.1	3.5	7.5	13.1
Mouse-Traverse	1.3 (*0.61)	2.0 (0.57)	4.0 (0.53)	6.4 (0.49)
Ultrasonic Positioning	1.4 (0.67)	2.1 (0.60)	4.0 (0.53)	6.5 (0.49)

* The man-hour comparison coefficient (MMCC) of technique vs. manual method

A best-fit equation, based on the data shown in Figure 37, is as follows:

$$y = 0.9\,x^{-0.16}$$

where

y	=	the man-hours comparison coefficient
x	=	the survey area (square meters)

A best fit equation, based on the data shown in Figure 38, is as follows:

$$y = 0.7x^{-0.11}$$

where

y	=	the man-hours comparison coefficient
x	=	the survey area (square meters)

However, for very large rooms (e.g., 1000 m^2), neither of these equations would hold true. It would be expected that this equation would hold true for areas up to approximately 200 m^2. For very large areas, limitations and variables (i.e., signal attenuation, assembly maintenance, data storage, manual survey short-cuts, etc..) of the automated systems would limit their field performance and efficiency. Figure 39 illustrates the extrapolated, best-fit lines for both automated techniques.

In summary, from the equation and the extrapolations shown in Figure 37, Figure 38, and Figure 39, it can be discerned that the optimum man-hours coefficient is approximately 0.40 for the largest of survey areas. Thus, by further evaluation of the man-hours comparison coefficient, it can be determined that the system can facilitate the survey of large rooms at about two and one-half times the rate of that of the manual

survey. In addition, the automated survey procedure includes nearly twice as many data points for statistical analyses and site assessments.

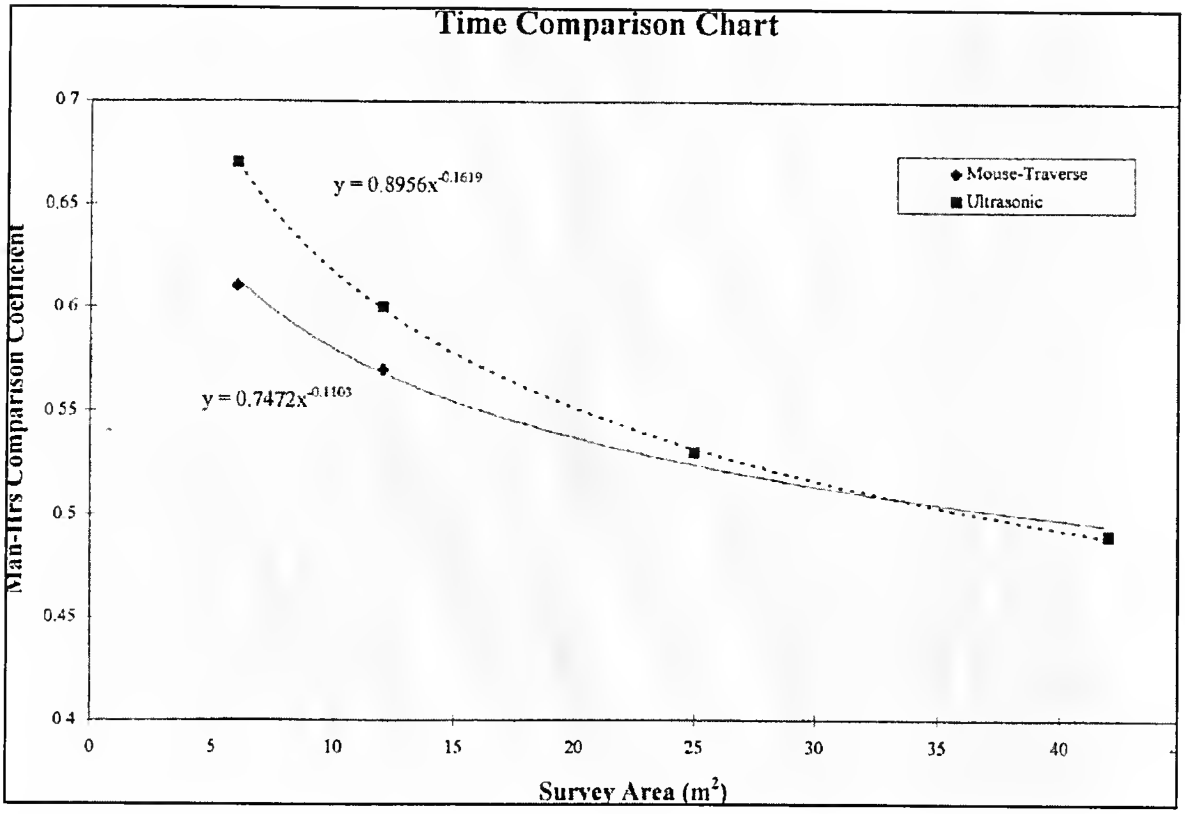


Figure 39. Mouse-traverse versus ultrasonic positioning.

While it is apparent that both of the automated systems provide a viable technique for larger survey areas, it was necessary to further evaluate their applicability for smaller survey rooms. Thus, a test involving the t-statistic and hypothesis testing was designed. Temporal data were kept on the time necessary to complete each survey unit in the 12 m^2 survey area. In essence, while in the process of surveying the area with the three techniques, the time data were recorded for each of the twelve survey units. A normalized

time allocation for the manual survey units was determined by adding one-twelfth of the total man-hours required to both grid and to determine the count/movement time corresponding to each survey unit. The time, in man-minutes per survey unit, for all three survey techniques is given in Table 8.

TABLE 8
SURVEY TIME PER SURVEY UNIT (12 m^2 area)

Survey Unit ($1m^2$) Number	Manual Survey Grid/Calculations (man-minutes)	Mouse-Traverse Positioning (man-minutes)	Ultrasonic Positioning (man-minutes)
1	18	12	13
2	17	10	11
3	19	10	10
4	18	10	10
5	17	10	10
6	17	10	11
7	18	10	10
8	17	10	10
9	18	11	10
10	17	10	10
11	19	10	10
12	17	10	11

To test to see if the time difference between the manual method and the two automated methods is significant, an experimental design, involving hypothesis testing and the t-test, was developed. The null and alternative hypotheses were as follows:

1. H_0: Mean time of manual method is equal to the mean time of the mouse-traverse automated method.

   H_1: Mean time of manual method is not equal to the mean time of the mouse-traverse automated method.

2. H_0: Mean time of manual method is equal to the mean time of the ultrasonic automated method.

   H_1: Mean time of manual method is not equal to the mean time of the ultrasonic automated method.

The significance level was set at 0.05, and the mean and the variance calculated for the time to complete a survey unit using the manual method were 17.5 minutes and 0.6 minutes, respectively. The mean and the variance for the mouse traverse technique was determined to be 10.2 minutes and 0.4 minutes while the mean and the variance for the ultrasonic technique was found to be 10.5 minutes and 0.7 minutes.

The critical t-statistic for a 0.5 significance level and 22 degrees of freedom was found in a t distribution table to be 2.1 (rounded-off). To test the null hypothesis (i.e., there is no difference in the time associated with the manual versus an automated survey technique), the following equation is used to determine the experimental t-statistic:

$$t\text{-}stat = \frac{Xbar_a - Xbar_b}{\sqrt{\dfrac{s^2}{n_a} + \dfrac{s^2}{n_b}}}$$

where

where	$t\text{-}stat$	=	t-statistic (calculated)
	$Xbar_a$	=	mean for first comparison value
	$Xbar_b$	=	mean for the second comparison value
	s^2	=	pool variance
	n_a	=	sample size for first comparison value
	n_b	=	sample size for the second comparison value

The t-statistic calculated for the comparison between the manual survey technique and the mouse-traverse technique was found to be 25.2 while the t-statistic for the comparison between the manual survey technique and the mouse traverse technique was calculated to be 21.2. Since both of the these test statistics are >> than 2.0739, it is possible to reject the null hypothesis and conclude that both of the automated techniques result in different survey time requirements than those for the manual method for rooms of 12 m^2 in area.

As an additional test, the automated methods were paired up against each other. The calculated t-statistic for this test was 1.0. Thus, since 1.0<2.1, it can be concluded that there is no temporal difference between the two automated methods when for a 12 m^2 area.

Real-Time Data Output (6 m^2 Survey)

Table 9 provides the complete data set taken for a 6 m^2 area survey utilizing the mouse-traverse positioning technique and sampling nine locations per survey unit. Table 10 provides the same data for the ultrasonic positioning technique. The data included in the tables are the same data that are available to the surveyor in real-time. Thus, a comprehensive analysis can be made in real-time. The minimum detectable activity and the 95 % confidence level background reading are given at the bottom of both of the tables.

TABLE 9
ALPHA CHARACTERIZATION SURVEY RESULTS (Mouse-Traverse)

Sample	X-Coord.(m)	Y-Coord.(m)	Gross CPM	Net CPM	DPM	DPM95
1-A	-0.01	0.02	2	1	39	
1-B	-0.01	0.49	8	7	39	
1-C	-0.01	0.99	12	11	58	
1-D	0.50	0.99	28	27	142	
1-E	0.52	0.49	8	7	39	
1-F	0.52	0.00	11	10	53	
1-G	1.00	0.01	15	14	74	
1-H	1.00	0.50	15	14	74	
1-I	1.01	1.00	6	5	39	
Avg. 1					62	81
2-A	1.01	1.00	4	3	39	
2-B	1.01	0.50	13	12	63	
2-C	1.00	0.01	18	17	89	
2-D	1.49	0.00	7	6	39	
2-E	1.49	0.51	17	16	84	
2-F	1.49	1.02	14	13	68	
2-G	1.99	1.05	7	6	39	
2-H	1.96	0.51	8	7	39	
2-I	2.00	0.02	10	9	47	
Avg.2					56	67
3-A	2.02	1.00	6	5	39	
3-B	2.02	1.49	20	19	100	
3-C	2.02	1.98	12	11	58	
3-D	1.50	2.00	13	12	63	
3-E	1.50	1.51	5	4	39	
3-F	1.50	0.99	9	8	39	
3-G	1.00	1.02	11	10	53	
3-H	1.00	1.50	11	10	53	
3-I	1.00	2.00	12	11	58	
Avg.3					56	67

MDA=39 cpm; Efficiency=19.6%; Background=1 cpm; CPM/DPM values per 100 cm^2

TABLE 9 (continued)
ALPHA CHARACTERIZATION SURVEY RESULTS (Mouse-Traverse)

Sample	X-Coord.(m)	Y-Coord.(m)	Gross CPM	Net CPM	DPM	DPM95
4-A	1.02	1.99	15	14	74	
4-B	1.00	1.52	12	11	58	
4-C	0.99	1.00	8	7	39	
4-D	0.51	1.01	9	8	39	
4-E	0.50	1.51	7	6	39	
4-F	0.49	2.01	12	11	58	
4-G	0.01	2.00	14	13	68	
4-H	0.02	1.50	12	11	58	
4-I	0.01	0.99	11	10	53	
Avg.4					55	62
5-A	0.02	1.99	15	14	74	
5-B	0.01	2.48	10	9	47	
5-C	0.01	3.00	10	9	47	
5-D	0.48	2.99	7	6	39	
5-E	0.52	2.50	5	4	39	
5-F	0.50	1.99	10	9	47	
5-G	1.01	2.00	8	7	39	
5-H	1.00	2.50	12	11	58	
5-I	1.01	3.01	13	12	63	
Avg.5					50	56
6-A	1.00	3.00	15	14	74	
6-B	0.98	2.49	22	21	111	
6-C	1.01	2.00	15	14	74	
6-D	1.51	1.98	14	13	68	
6-E	1.50	2.48	8	7	39	
6-F	1.49	2.99	7	6	39	
6-G	2.00	3.02	5	4	39	
6-H	2.01	2.49	6	5	39	
6-I	2.00	2.01	9	8	39	
Avg.6					58	71

MDA=39 cpm; Efficiency=19.6; Background=1 cpm; CPM/DPM values per 100 cm^2

TABLE 10
ALPHA CHARACTERIZATION SURVEY RESULTS (Ultrasonic)

	X-Coord.(m)	Y-Coord.(m)	Gross CPM	Net CPM	DPM	DPM95
1-A	-0.01	0.02	5	4	39	
1-B	-0.01	0.49	13	12	63	
1-C	-0.01	0.99	12	11	58	
1-D	0.50	0.99	22	21	111	
1-E	0.50	0.49	8	7	39	
1-F	0.50	-0.02	14	13	68	
1-G	1.00	-0.01	17	16	84	
1-H	1.01	0.49	15	14	74	
1-I	0.99	0.99	7	6	39	
Avg. 1					64	79
2-A	1.00	0.99	7	6	39	
2-B	1.00	0.49	14	13	68	
2-C	1.01	0.02	20	19	100	
2-D	1.50	-0.02	9	8	42	
2-E	1.51	0.49	17	16	84	
2-F	1.51	0.99	10	9	47	
2-G	1.97	0.97	7	6	39	
2-H	2.01	0.49	7	6	39	
2-I	2.00	0.48	12	11	58	
Avg.2					57	71
3-A	2.01	0.99	6	5	39	
3-B	2.01	1.50	21	20	105	
3-C	2.00	1.99	12	11	58	
3-D	1.51	1.99	13	12	63	
3-E	1.51	1.50	7	6	39	
3-F	1.51	0.99	11	10	53	
3-G	1.00	0.99	10	9	47	
3-H	1.00	1.47	11	10	53	
3-I	1.00	2.00	12	11	58	
Avg.3					57	69

MDA=39 cpm; Efficiency=19.6%; Background=1 cpm; CPM/DPM values per 100 cm^2

TABLE 10 (continued)
ALPHA CHARACTERIZATION SURVEY RESULTS (Ultrasonic)

Sample	X-Coord.(m)	Y-Coord.(m)	Gross CPM	Net CPM	DPM	DPM95
4-A	1.01	2.01	14	13	68	
4-B	0.99	1.50	10	9	47	
4-C	1.00	0.99	8	7	39	
4-D	0.50	0.99	11	10	53	
4-E	0.50	1.50	10	9	47	
4-F	0.50	2.00	14	13	68	
4-G	-0.01	2.01	13	12	63	
4-H	-0.02	1.49	12	11	58	
4-I	-0.01	0.99	7	6	39	
Avg.4					54	61
5-A	-0.01	1.99	15	14	74	
5-B	-0.01	2.46	9	8	42	
5-C	-0.01	3.01	12	11	58	
5-D	0.50	3.00	8	7	39	
5-E	0.50	2.50	7	6	39	
5-F	0.47	2.00	12	11	58	
5-G	1.00	1.99	11	10	53	
5-H	1.01	2.48	12	11	58	
5-I	1.01	2.97	12	11	58	
Avg.5					53	60
6-A	1.01	2.98	15	14	74	
6-B	1.01	2.51	21	20	105	
6-C	1.00	2.00	15	14	74	
6-D	1.51	2.00	13	12	63	
6-E	1.51	2.51	10	9	47	
6-F	1.49	3.01	8	7	39	
6-G	2.01	3.00	10	9	47	
6-H	1.99	2.50	7	6	39	
6-I	2.01	1.99	9	8	42	
Avg.6					59	73

MDA=39 cpm; Efficiency=19.6; Background=1 cpm; CPM/DPM values per 100 cm^2

The site mean and standard deviation, calculated at the 95% confidence level, were 69 dpm/100 cm^2 and 7 dpm/100 cm^2, respectively, for the 6 m^2 area surveyed using ultrasonic positioning. For the 6 m^2 area surveyed using the mouse-traverse technique, the site mean was determined to be 68 dpm/100 cm^2 and the standard deviation was calculated to be equal to 8 dpm/100 cm^2. These values are less than the 100 dpm/100cm^2 release criteria established for thorium-230. All of the unit means were within the criteria.

Three-dimensional profiles, generated from the spatial and magnitude data sampled during the survey, are given in Figure 40 and Figure 41. Figure 40 shows the three-dimensional plot of the data from the mouse-traverse survey of a 6 m^2 area. Figure 41 illustrates the data taken during the ultrasonic survey of a 6 m^2 survey area. It is possible to generate these drawings anytime during the survey process, thus, allowing for real-time, analytical assessments.

Figure 42 illustrates a discrete block plot from a manual survey of the same area.

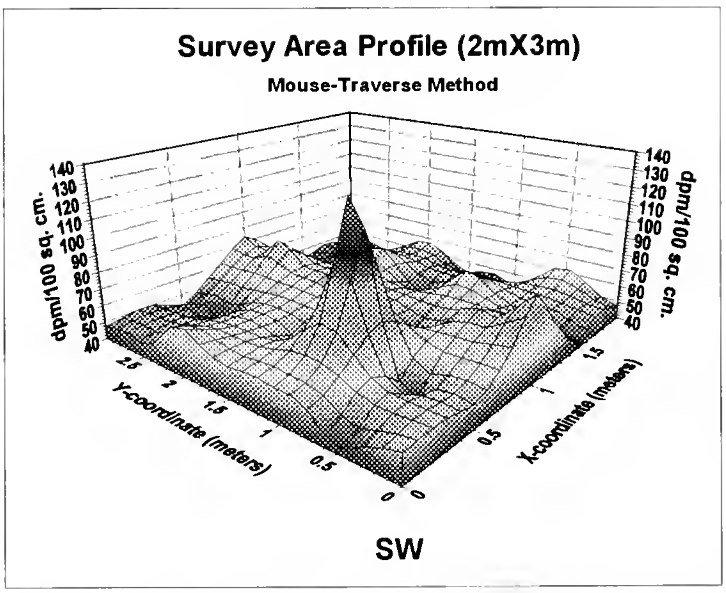


Figure 40. Contour data from mouse-traverse survey.

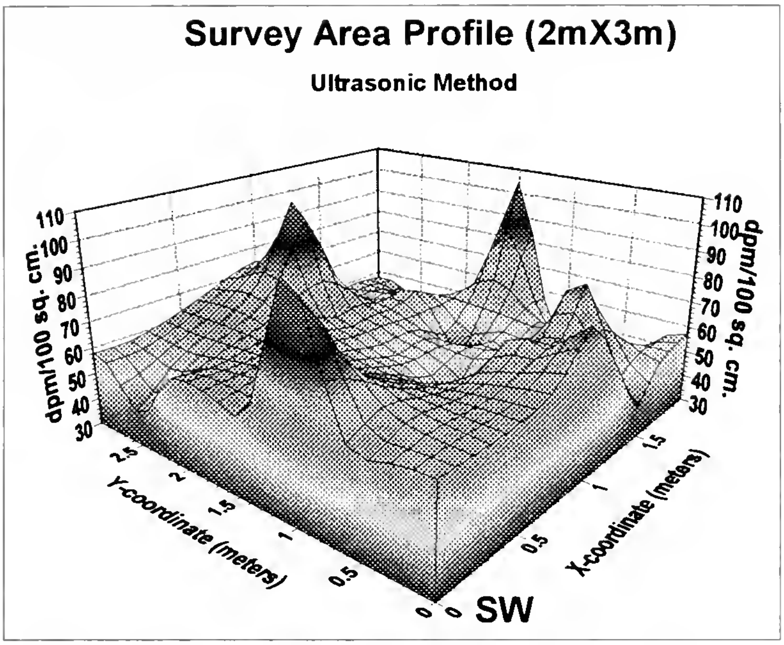


Figure 41. Contour plot of data from ultrasonic survey.

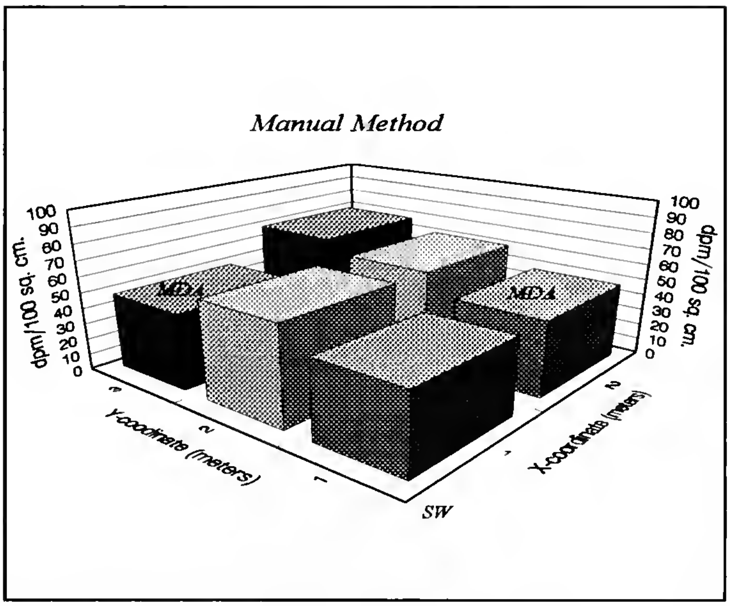


Figure 42. Discrete plot from manual survey.

However, the radiological survey meter and detector used were different. The MDA of the manual unit was determined to be 54 cpm, and the data plotted in the figure are the discrete mean values from each survey unit. By performing a comparison between the automated techniques and the manual method, it can be concluded that the automated results are superior. Note that the manual method even resulted in the graphing of data values at the MDA level in one-third of the cases. In addition, the plot of the manually determined data does not indicate any of the elevated levels. Thus, the points that do exceed the standard criterion are not identified for the given survey.

Detector Repeatability

For quality control purposes, ten percent of the points sampled were counted twice (Berger, 1992). In order for the data to be considered acceptable, the relative percent difference (RPD) between the two samples must be less than 20 (ORISE, 1993). Table 11 provides the activity levels at the repeat points taken during the ultrasonic 6 m^2 survey. In addition, it gives a RPD value for the data.

The data obtained on detector repeatability from the mouse-traverse survey resulted in RPD values comparable to those found during the ultrasonic survey. The RPD values for detector repeatability for the manual technique were not calculated because the repeat values taken by the survey technicians were from random locations. However, the technicians did complete repeat counts at a sufficient number of locations to satisfy specifications.

TABLE 11
DETECTOR REPEATABILITY (6 m^2)

LOCATION	SAMPLE 1 (DPM/100 cm^2)	SAMPLE 2 (DPM/100 cm^2)	RELATIVE % DIFFERENCE
0.00, 1.00	39	39	0
1.00, 3.00	58	74	24
1.00, 0.00	84	100	17
1.00, 0.50	74	68	9
1.00, 1.00	39	39	0
1.50, 1.00	48	53	9
2.00, 1.00	39	39	0
2.00, 2.00	58	42	32
1.50, 2.00	63	63	0
1.00, 1.00	47	39	19
1.00, 1.50	53	47	12
1.00, 2.00	58	68	17
0.50, 2.00	68	58	17
0.00, 2.00	63	74	16
1.00, 2.00	74	58	24

Three out of the fifteen repeat points resulted in RPD values exceeding the 20% criteria. Thus, those three points would need to be repeated for a final status survey. The mean RPD for the data was calculated to be 12% with a standard deviation of 8%. The mean RPD for the mouse-traverse survey was 11% with a standard deviation of 8%.

Conclusions of Field Implementation Exercise

In summary, the two automated positioning techniques, ultrasonic positioning and mouse-traverse positioning, provided viable alternatives to the manual survey methods currently employed at indoor radiological sites. The total automated system made it possible to make accurate assessments, of both space and magnitude, in real-time. In essence, the system, as designed, eliminated the need for manual gridding and manual calculations. Thus, since the time requirements for gridding and performing site calculations are a major component of the survey process, the system made it possible to complete each survey more efficiently.

Some of the system problems identified during the surveys include:

1. The trackball/mouse design has durability limitations.
2. The range capabilities of the ultrasonic device was limited to 10 meters.
3. It was difficult to get the system apparatus into "tight" places.
4. The learning curve is longer than anticipated for use of the system.
5. Due to having only one serial port, a data selector was necessary.
6. The positioning techniques required substantial QC/QA measures.
7. Obstacles or "rough" floors present positioning problems to be resolved.

A list of the major conclusions drawn from the field surveys were as follows:

1. Both automated positioning techniques provided an effective and efficient means for facilitating the indoor radiological survey process.
2. Even for smaller areas, the automated techniques are viable.

3. For larger area rooms, both automated techniques provide the capability of sampling nearly twice as many points as that of the manual procedure in 40% of the time.

4. The temporal characteristics of both of the automated techniques are essentially the same.

5. An equation can be developed that describes the temporal characteristics of the automated methods for larger area rooms.

6. The spatial accuracy characteristics of both automated techniques are comparable.

7. The spatial repeatability of the ultrasonic technique exceeds that of the mouse-traverse technique.

8. Data profiles can be generated in real-time for in-field analytical assessments.

9. The characterization survey for Th-230 by the automated system resulted in criteria compliance for the area as did the manual procedure.

10. The RPD analysis uncovered three out of fifteen points beyond the 20% criteria.

11. Future research should be directed at extending the range and flexibility of automated positioning survey system.

12. On-site changes to the computer program were sometimes necessary but could be performed in a timely fashion (e.g., 3-5 minutes).

13. Both automated techniques provided an improvement in data quality over the traditional, manual survey method.

CHAPTER 6
SUMMARY AND CONCLUSIONS

The radiological survey process is a critical and aggressive component of the total decommissioning process. Its protocol requires the compilation and management of a large number of data points. The more accurately, efficiently, and effectively the survey can be accomplished, the more cost efficient will be the determination of further planning of the decommissioning process. In addition, the integrity of the radiological survey process can be utilized as the baseline to gauge the overall program's success. An automated and integrated method, as the one presented in this dissertation, can help to facilitate the timely yet accurate identification, location, and quantification of radioactivity levels at the various sampling sites.

Review of Objectives

The primary goal of this research was to show that a viable automated method of performing radiological surveys could be developed and field tested. The following are a list of the expected objectives and results of this research as identified early on in the planning process:

1. The creation of an automated environmental monitoring and assessment system capable of accurately performing indoor radiological surveys to current specifications.

2. A dramatic reduction in the temporal component of the survey and total radiological decommissioning process due to the major enhancements made over traditional survey methods.

3. The integration of both spatial and magnitude data through the use of new computer software and hardware technologies.

4. The development of a portable system capable of being easily adapted to changing field conditions.

5. The development of standard operating procedures and quality assurance/quality control procedures to insure the optimum use of the system.

6. The development of a system that would be easy to understand and use, thus requiring a minimum of re-training of technicians and other site personnel.

7. The integration of the system that would provide both an efficient and effective utilization of the latest technologies for providing real-time data analysis and assessment, without the need to wait for raw data manipulations.

8. The development of a field-friendly, survey apparatus for a wide range of survey applications.

Summary

From the experiences realized during the course of the field surveys, the automated system has met, with a few reservations, all of the above expectations. As expected, data points gathered from both field studies and controlled lab studies were analyzed and evaluated in real-time. This was accomplished through the integration of current computer software and hardware technologies, advanced radiological survey instrumentation, and automated spatial positioning devices. While most of the data assessed were from alpha surveys, minor changes to the computer protocol would make it possible to perform other radiological surveys (i.e., gamma, beta).

The results from the pilot gamma survey, the Th-232 site survey, and the field alpha survey all suggested that the time component of performing the survey process can be significantly reduced with the automated survey apparatus. In addition, the real-time data analysis, made possible by utilizing this integrated effort, provided the mechanism for all involved parties to make critical assessments and decisions while still in the field. One evident system drawback was that the field application of the system, as designed, was limited to floor and wall surveys. Surveys that are performed above the ceiling cannot be accomplished with this apparatus. However, since the Ludlum Model 2350 has datalogging capabilities, it can be temporarily disconnected from the system and used above the ceiling. The Model 2350 can read and log 256 points, which can then be downloaded to the computer while still in the field.

Standard operating procedures and quality assurance/quality control procedures were written that included essential parameters from previous efforts while still providing the necessary modifications to integrate the new techniques in an effective and orderly fashion. A survey traverse scheme was developed that included sampling, repeat, and control points. The procedures called for the collection of nine points per survey unit, instead of the traditional five points per survey unit criteria. The larger number of sampling locations would increase the statistical confidence per survey unit, thus leading to a more accurate total survey assessment.

From the data gathered on the alpha floor surveys, an equation was estimated that could be used to extrapolate the time component for rooms of larger surface area. The

equation included a time ratio coefficient that related the automated and manual surveys (i.e., t_a/t_m). In theory, the equation suggests that as the room area is increased, the temporal comparison becomes more and more definitive and approaches zero. However, due to inherent systemic problems and manual survey shortcuts, in practice, the ratio would not approach true zero. Instead, the data suggested that optimum performance would result in approximately twice as may points gathered in about 40% the normal required survey time.

The spatial quality control checks showed that both automated techniques provided acceptable accuracy and repeatability results. In addition, while compared with each other, the two automated techniques could not be shown to provide significantly different time efficiency results; both methods were statistically shown to be significantly more time efficient than the manual technique. Detector repeatability was determined for about 15% of the sampling points. This study showed that the detector was not capable of meeting the relative percent difference (RPD) criteria for approximately 20% of the data points. Thus, for final status surveys, 20% of the data points collected would be required to be re-sampled.

The Windows environment and the Visual Basic programming software provided the user with the necessary program linking capabilities as well as a viable software graphical interface. During the course of the survey, other Windows-based packages (e.g., Access, Excel, Stanford Graphics) were dynamically linked to provide adequate data management, integration, and visual outputs. While the learning curve for the beginning user may be quite substantial in cases where the technician is not computer literate, most

of the survey technicians would find the applications software to be very user-friendly and thorough. The control software was written to be icon-based, and all of the screens simulate the front of instrument control panels.

The final applications program for the alpha automated survey ended up to be over 8100 lines of computer code. However, small modifications and only minimal increases/decreases in code provide an almost endless array of field survey capabilities. While the main code that was written was for the total system integration and control, special routines were written to include such tasks as equipment calibration, configuration, and set-up. The user is supplied with all the icon-based selection screens that are imperative to optimum field adaptability and flexibility conditions, and the user will not be required to modify the computer program in the field.

It was determined early on during the planning process that the system should not be limited to only radiological surveys. The automated survey system can be applied to other types of environmental surveys such as analytical industrial hygiene surveys and hazardous waste site location/surveying. Thus, an equipment selection screen appears at the beginning of each new survey configuration. This makes it possible for the surveyor to choose his/her instruments and/or positioning devices.

While the system was primarily developed to perform indoor surveys, the associated software and the hardware was developed to be applicable to both indoor and outdoor site surveys. One of the two PCMCIA slots was configured for a portable global positioning system (GPS). As was concluded early on in this paper, the GPS provides the best overall positioning technique for occasions when the system would be used outside.

The National Instruments DAQ-700 data acquisition card provided the necessary link between the ultrasonic positioning device and the control program. Since the use of this card was a beta venture, a major concern was its inherent limitations. However, the card did not cause any identifiable systematic problems during the course of the system development or during any of the field surveys. However, it was possible that its power requirements limited the field lifetime of the notebook's battery.

The Ludlum Model 2350 Ratemeter/Datalogger was an essential component to the success of the project. The unit was already equipped with an RS-232 port which could be connected directly to the notebook computer's serial port. The computer and the instrument were then both configured to handshake. The Model 2350 also provided the user with the capability to temporarily save data without the aid of the computer. In addition, there were sixteen different detectors that were compatible with the Model 2350, thus, making it possible to sample various field conditions.

Limitations

While the system provided many new capabilities, it still has several design and operating limitations. For one, it would be extremely difficult to use the system in rooms that were not primarily "stripped-down". Equipment and obstacles cannot only pose a problem for maneuvering but also can attenuate the ultrasonic signals, thus, leading to erroneous spatial data. In addition, the apparatus as designed will not reach certain places in the room. The standard operating procedures even included an 0.5 meter allowance, from the walls and corners, for starting the survey. Thus, there is a necessary yet problematic systematic bias against sampling close to objects and walls.

A possible way to alleviate some of the problems, that are a direct result of the physical characteristics of the survey apparatus, would be to wear most of the survey system as a "front-pack" and to push or guide along, in a controlled fashion, the positioning devices. The "front-pack" design would resemble the vendor carrying packs worn by stadium vendors. The "front-pack" should have enough room for the notebook computer, the Ludlum Model 2350, and any necessary accessories. In order to maintain spatial accuracy, the positioning devices would need to be mounted in a fashion that would accommodate 90 degree interval movements.

Both of the automated positioning techniques, ultrasonic positioning and mouse-traversing, have their limitations. In addition to obstacle attenuation problems, the ultrasonic device is only accurate up to around ten meters. Thus, in order to perform accurate surveys of larger areas, the operating procedures must incorporate a survey mechanism, such as a tripod arrangement, that will accommodate the limited range. While the mouse-traverse technique can be used for greater ranges, it lacks durability and ruggedness. Several times during the survey process it was necessary to clean the trackball free from the dirt accumulated from the floor. In addition, since mouse-traversing is a relative positioning technique, it can never be utilized on floors that are not level. Basically, the mouse-traverse technique is limited to indoor environments with relatively clean tile flooring.

From these observations, it is evident that the key to the improvement of the spatial component of the automated process is the future integration of a positioning

device that is capable of extended ranges of high accuracy measurements. While both of the tested spatial positioning techniques served the purpose for surveys completed in smaller rooms, some procedural modifications are necessary to utilize either ultrasonic positioning or mouse-traversing in very large rooms.

As they become more affordable, hand-held inertial positioning systems would provide an optimum replacement for either of the two described techniques. However, their prices are still in the $30,000 range. Another viable positioning alternative involves a recent advancement in laser technology that has resulted in the development of a portable, inexpensive (e.g., $1400) hand-held laser measuring device. This laser positioning device has an analog output and a range of 300 feet with +/- 3mm accuracy.

Another major limitation of the survey unit was the existence of only one serial port on the computer. This required some additional computer code to be written as well as the use of a multiplexer to switch between various serial devices (e.g., Ludlum Model 2350-to-mouse-to-Ludlum 2350, etc...). In addition, this switching process resulted in a marginally greater time component associated with the mouse-traverse technique.

An expense limitation would be realized if the unit was going to be utilized on only small-scale surveys (i.e., 10m X 10m rooms). The total cost of the automated survey system, as designed, is approximately $8,000. However, if the system will be primarily used on large-scale surveys, the system will quickly pay for itself in survey time saved. In addition, purchase justification can be partially based on the data integrity improvements that will be expected.

Significant Conclusions

The major conclusions from this research are as follows:

1. The system accommodated real-time data tracking, and a large number of measurements were compiled and managed effectively.

2. Both automated techniques provided the capability of sampling approximately twice the number of locations in about 40% of the required time necessary to perform manual surveys.

3. The accuracy and repeatability characteristics of both ultrasonic positioning and mouse-traversing were excellent.

4. The repeatability measurements for ultrasonic positioning were marginally better than that of mouse-traversing. This was due primarily to the inherent systemic characteristics associated with relative positioning techniques.

5. The system made it possible to reduce the time necessary to perform alpha characterization surveys in the field. There is no reason to believe that the automated system would perform any differently for gamma/ beta surveys or for final status surveys.

6. The system can make it possible to reduce the total time associated with performing the survey component of the decommissioning process.

7. The automated system will help to facilitate the decontamination component of the total process.

8. Decommissioning site personnel should not only be experienced in site characterization but also be computer literate in order to take advantage of the capabilities of the computer.

9. An automated system of this type should not be limited to performing only indoor radiological surveys. This system could be used effectively outdoors as well as for other types of surveys (i.e., environmental, industrial hygiene, hazardous waste site, etc..).

10. While positioning techniques such as laser and inertial ranging are still quite costly, they would provide an overall improvement over ultrasonic and relative positioning techniques for field surveys.

11. In the short-term, automated methods of data collection and analysis can still be time costly because of the learning curve involved. In addition, the initial cost of the computer equipment could be a constraint.

12. In the long term, automated surveys, using the latest computer and instrument technologies, can be a cost-effective alternative to the laborious, manual methods of survey recording and data analysis.

APPENDIX A
CRITERIA FROM REGULATORY GUIDE 1.86

TABLE A-1
ACCEPTABLE SURFACE CONTAMINATION LEVELS

Nuclide[a]	**Average**[b,c]	**Maximum**[b,d]	**Removable**[b,e]
U-nat, U-235, U-238 and decay products	5000 dpm/100 cm^2	15,000 dpm/100 cm^2	1000 dpm/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-238, I-125, I-129, Ac-227	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90, Ra-223, Ra-224, U-232, I-126, I-131, I-133	1000 dpm/100 cm^2	3000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters except Sr-90 and others noted above	5000 dpm/100 cm^2	15,000 dpm/100 cm^2	1000 dpm/100 cm^2

[a]Where surface contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for alpha and beta-gamma emitting nuclides should apply independently.
[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors.
[c]Measurements of average contaminant should not be averaged over more than 1 square meter.
[d]The maximum contamination level applies to an area of not more than 100 cm^2.
[e]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with a dry filter and assessing the amount of radioactive material on the wipe with the appropriate instrument of known efficiency.

APPENDIX B
MANUAL SURVEY STANDARD OPERATING PROCEDURES

I. Purpose:

To describe the general approach of performing the manual indoor radiological survey.

II. Responsibilities:

1. The site coordinator is responsible for procedural implementation.
2. The survey health physicist(s) are responsible for procedural compliance.

III. Prerequisites:

1. Comply with applicable RWP or operating procedure requirements.
2. All survey instruments will be checked for proper operation before use.
3. Surveys shall be performed by trained and qualified technicians.

IV. Test Equipment, Tools, and Supplies:

1. Appropriate radiation detection equipment and check sources.
2. Survey forms and maps.
3. Required personal protective equipment.
4. Appropriate personal dosimetry.
5. Smears and transport containers.

V. Action Steps:

1. Planning Health Physics Surveys:
   a. Determine the type of survey.
   b. Review the applicable RWP or Standard Operating Procedures.
   c. Evaluate what radionuclides are involved in the task and their form.
   d. Perform/ensure QC and performance checks are complete.
   e. Prepare the survey map, showing all walls, equipment, and reference directions.
   f. Complete applicable sections of the survey form.

2. Performing Inspections During Radiological Surveys:
   a. Visually inspect glovebox gloves for defects.
   b. Visually inspect area for proper storage of radioactive materials.
   c. Check portable detection instruments for data of calibration and operability.
   d. Visually inspect for abnormal conditions and proper posting.
   e. Visually inspect and update all radioactive material tags whenever the data on the tag is > 12 months and/or anytime the item is resurveyed.

3. Determining Radiation Levels:
   a. Perform general area radiation readings at about one meter above floor.
   b. Perform contact radiation readings at 0.5 meter intervals and determine boundary placement where appropriate.
   c. Use gridding to divide the survey area into 1 meter by 1 meter survey units. At least 5 samples from this area shall be taken.
   d. Record all radiation readings on the survey form.
   e. Complete all applicable sections of the survey form.

4. Determining Contamination Levels:
   a. Perform direct contamination survey of locations most likely contaminated and at grid locations (e.g., 5 points per 1 m^2).
   b. Perform surveys of areas where work is to be done.
   c. Total surface contamination levels are documented the same as loose surface contamination levels.
   d. Large area wipe levels in dpm/wipe (single line indicates the starting and stopping points and path taken).

VI. Acceptance Criteria:

1. Acceptance criteria can be found in Regulation Guide 1.86.

VII. Post-Performance Work Activities:

1. Ensure area is properly posted.

2. Ensure all forms are completed.

3. Note abnormal conditions on the survey form.

4. Return all survey forms to the site coordinator for review.

5. Health Physics supervision shall review and approve all surveys.

VIII. Records:

1. The radiological survey map is a QA record and shall be transmitted to the records management department per procedures.

2. Proper records shall be submitted to NRC or other appropriate parties.

APPENDIX C
INSTRUMENTATION CALIBRATION AND OPERATIONAL CHECK-OUT

General Information

I. Purpose:

To describe the general approach to calibration and operational check-out of all survey instruments and automated positioning equipment.

II. Responsibilities:

1. The site coordinator is responsible for procedural implementation.

2. The survey team personnel are responsible for procedural compliance.

III. Procedure:

A. Calibration

1. Instruments to be used for quantitative measurements are source calibrated and an operational check-out is performed prior to each specific site survey. Necessary correction factors can then be determined to establish acceptable operating criteria.

2. Radiological measurement instruments are to be calibrated with standards traceable to the National Institute of Standards and Technologies (NIST) or other industry recognized standards organizations.

3. Positioning devices are to be calibrated, prior to each specific site survey, with measurement standards traceable to the National Institute of Standards and Technologies.

4. Operational check-outs are to be performed on all instruments used for qualitative scanning prior to each specific survey.

5. Instruments are to be calibrated and checked out as an instrument/detector combination and will be used that way during the survey.

6. Threshold values are based on manufacturer specifications.

7. All other accessory equipment associated with the instrument/detector and survey operations shall be checked prior to the survey.

B. Operational Check-out

1. The following equipment associated with the automated survey will be operationally checked out prior to the site survey:

   a. Detectors
   b. Cables
   c. Computer
   d. Data acquisition card
   e. Rangefinders/circuitry
   f. Portable ratemeter
   g. Check sources
   h. Computer program
   i. All interfaces
   j. Serial multiplexer

2. The following procedure applies to the operational check-out of the survey instrument and will be performed on a daily basis as a quality control function.

   a. Attach the detector to the instrument.
   b. Turn on instrument and check batteries.
   c. Adjust the threshold and high voltage values to the predetermined values.
   d. Place the calibrated check source in contact with the detector.
   e. Determine and record the count rate.
   f. Check the audible output.
   g. Determine and record the background count rate.
   h. Compare source and background levels with previous records.
   i. Unacceptable changes must be corrected before use.

3. The following procedure applies to the operational check-out of the automated survey components (i.e., computer, positioning devices, data switches, etc..):

   a. Check all equipment-to-computer connections for continuity.
   b. Turn on computer and check battery charge for maximum charge.
   c. Access site information from the database and check out survey software from the Visual Basic program.
   d. Check mechanical and electrical connections between the automated positioning devices and transducers and necessary interfaces.
   e. Turn on ultrasonic positioning device and check power source.
   f. Check operation of serial multiplexing device by switching from ratemeter connection to mouse connection and back again.

Calibration of Ludlum 2350 Ratemeter/Datalogger

I. Purpose:

To describe the procedure for calibrating the Ludlum 2350 Ratemeter/Datalogger or comparable unit.

II. Responsibilities:

1. Implementation of this procedure is the responsibility of the site coordinator.

2. The following of this procedure is the responsibility of the survey team.

III. Equipment:

1. Ludlum Model 2350 Ratemeter/Datalogger.
2. High calibrated source.
3. Low calibrated source.
4. Two calibrated sources that are comparable in size.
5. Hand-held programming terminal.
6. Appropriate detector.
7. Cables.
8. Record forms.
9. Ludlum Model 2350 Operations Manual

IV. Procedure:

A. Operational Check-out Procedure

1. Turn on Ludlum 2350 and check batteries; replace if necessary.

2. If the batteries must be replaced, a "cold start" must be performed.

3. To perform a "cold start", command 'SSR' must be entered from the terminal.

4. The "cold start" will cause the Model 2350 to resume operation in the default.

5. Turn off the Ludlum Model 2350 and connect the appropriate detector.

B. Terminal Configuration

1. The following settings must be programmed into the hand held terminal before it can be used in any of the calibration routines:

   * Baud = 9600
   * Data bits = 8
   * Parity = ignore
   * Display pe = enabled
   * Repeat = fast
   * Echo = enabled
   * Handshake = enabled
   * Self test = disabled

2. After this initial set-up, all that needs to be done to operate the terminal is to enter the command code, followed by the ENTER key and then the F5 key.

3. Software, supplied with the unit, can be used in lieu of the terminal when operated from a computer.

4. The Ludlum 2350 Operation Manual should be referred to for any further clarification.

C. Dead Time Calibration Procedure

1. Configure the hand-held terminal for use with the Model 2350 (See Ludlum 2350 Operation Manual).

2. Use the terminal to enter the command 'SSD' to enter the routine.

3. Shield all sources in close proximity to the detector.

4. Enter the command 'C' to start the background count for a baseline determination (the background should be as low as possible). The minimum recommended count time, for statistical validity, should be 30 seconds.

5. Choose two size comparable calibrated sources that in combination will provide about 10% to 20% dead time losses.

6. After the count is completed, place one of the two comparable sized sources by the detector and enter the command 'C'.

7. After this count is complete place the second comparable source next to the other source and enter the command 'C'. This will be saved as SAMPLE 1+2.

8. After completion of this count, remove the first source and count only the second source by entering once again the command 'C'.

9. The system dead time is then calculated by the unit and displayed for user confirmation on the display screen.

10. The user can then save the value by entering 'Y' or can dismiss the new dead time value by entering 'N'.

D. Calibration Constant Routine

1. Select the calibration constant routine by entering 'SSK'.

2. Enter the value of the low-level calibrated sample.

3. Enter the value of the high-level calibrated sample.

4. Place the detector at the low sample point and enter 'C'. The minimum count rate recommended for the low sample is 2000. A 30 second count time should provide this rate.

5. Place the appropriate detector at the high sample point and start the count by entering the command 'C'.

6. The unit's screen will the prompt the user to enter 'Y' if the value for the constant looks reasonable or a 'N' if the value does no look reasonable. If a 'N' is entered, the unit will recall the previous value for the calibration constant.

Calibration and Check-Out of a Gamma Scintillation Detector

I. Purpose:

To describe the procedures for operational check-out of gamma scintillation detectors compatible for use with the Ludlum 2350 ratemeter.

II. Responsibilities:

1. The site coordinator is responsible for assuring procedural implementation.

2. The survey technician is responsible for following this procedure.

III. Equipment:

1. Ludlum Model 2350 Ratemeter/Datalogger
2. Sodium iodide detector: Ludlum Model 44-10 High Energy Gamma Detector or equivalent.
3. Necessary instrument cables/connectors.
4. Record forms (manual hard copies or computer database records)
5. Calibration source.
6. Check source.

IV. Procedure:

1. Turn on the Model 2350, check batteries, and replace if necessary.

2. Enter the command 'SVD1' to select the correct display by using either the hand held terminal or the computer keyboard.

3. Set the high voltage to approximately 900 by entering the command 'H900'.

4. Turn the Model 2350 off and connect the gamma scintillation detector.

5. Turn the instrument back on .

6. A background level should be determined by taking a sample of 8-10 readings and averaging them. The count time should be set at a minimum of 30 seconds and the ratemeter should be set to its slowest response rate.

7. The computer program provides the user with the ability to take the necessary background rates and averages the values automatically or the user can opt to use the hand held terminal and follow the procedures in the Ludlum 2350 Operations Manual. The automatic methods is explained in a later section under the Survey Standard Operation Procedures.

8. Record the average count rate on the first data line of the Instrument Operational Checkout Form (Figure C-1, or equivalent).

9. Determine the acceptable background response limits by setting the Ludlum 2350 to fast response. Record the lowest and highest values observed.

10. Choose a check source with a gamma energy distribution that is representative of the expected radioactive material contaminating the survey site.

11. Determine the check source count rate by placing the source in front of the detector. Record the count rate and determine the +/- 10% variation of the check source count rate as the source response limits.

12. Again, the hand held terminal and proper Ludlum 2350 Operations Manual adherence can be used to perform this procedure or the computer program written for the survey standard operating procedures can be utilized.

13. It is essential that a record of this data and the check source accompany the instrument to the field survey site.

14. A cross-calibration, utilizing a pressurized ionization chamber (PIC), is also recommended to increase instrument confidence.

INSTRUMENT OPERATIONAL CHECK-OUT FORM

INSTRUMENT TYPE ______________ DETECTOR TYPE ______________

INSTRUMENT # ______________ DETECTOR # ______________

SITE ______________ EFFICIENCY ______________

VOLTAGE ______________ THRESHOLD ______________

	Check Out Date/Time	Background (c/__m)	*Source Type: ID#: c/__m	** Source Type: ID#: c/__m	Checked Out By	Comments (see reverse)
						ORAU Data
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						

Background Response limits ______ to ______ c/m

*Source Response limits ______ to ______ c/m

**Source Response limits ______ to ______ c/m

☐ DATA REVIEWED

Figure C-1. Instrument Operational Check-Out Form.

Calibration and Operational Check-Out of the Alpha Scintillation Detector

I. Purpose:

To describe the proper procedures for the calibration and operational check-out of the alpha scintillation detector.

II. Responsibilities:

1. The site coordinator or site safety officer is responsible for the proper implementation of the following procedure.

2. The survey technician(s) are responsible for proper procedural adherence.

III. Equipment:

1 Ludlum Model 2350 portable ratemeter/datalogger, or equivalent.
2. Alpha ZnS detector: Ludlum Model 43-89 Alpha/Beta Scintillator, or equivalent.
3. Necessary cables and connectors.
4. Record forms (manual hard copies or computer database records).
5. Appropriate calibration sources.
6. Check sources.

IV. Procedure:

1. Attach the alpha detector to the Ludlum Model 2350 or equivalent.

2. Check the battery voltage and replace if necessary.

3. Adjust the threshold setting for the instrument/detector combination by entering the command 'T1000' from the 'SVD1' display (See Ludlum 2350 Operations Manual for further clarification). This sets the threshold to 1000 for the construction of the plateau curve.

4. Face the detector to a source of light to detect for leaks. The light illumination through a leak in the mylar will cause the detector to

register many counts. If this occurs, replace the mylar face on the detector.

5. Construct the plateau curve by performing the following:

   a. Place the detector on an alpha source of greater than 50,000 dpm.
   b. Adjust the high voltage by entering the command 'H???' at select increments beginning at around 50 volts until the meter begins to register counts. The meters audible speaker can be used to "hear" the disintegrations or the unit's display can be observed.
   c. The counts should be accumulated for 30 seconds and recorded along with its associated voltage.
   d. Increase the voltage in intervals of 50 volts and repeat the above procedure until the count rate begins to increase rapidly with increased voltage.
   e. Do not increase the voltage into the continuous discharge range as damage to the instrument or detector may occur.
   f. Prepare a graph of the count rate versus the high voltage. The graph should consist of a relatively flat section where there is little increase in count rate over a voltage range of somewhere between 200 and 300 volts. On both sides of the "flat" region with very little slope are regions of steep slopes. The flat region is known as the plateau region. See Figure C-2 for a graph of a plateau curve.
   g. A voltage level should be selected at around the midpoint of the plateau region and use this as the high voltage setting for the instrument. For the Ludlum 2350, the high voltage reading can be set by entering the command 'H???. It is expected that this value will be between 900 and 1200 volts.

6. Record the operating voltage and the threshold on the calibration form (Figure C-3) or save the record in the computer program as site data and/or in the database.

7. Determine the detector background count rate for approximately 5 minutes. Record the background on the calibration form or save in the computer program or database under site information.

8. Select a count time of 60 seconds for alpha emitters such as thorium-230, Ra-226, other transuranics, etc. (i.e., those radionuclides with acceptable average surface contamination <100 dpm/100 cm^2 to specification). On the other hand, a count time of 30 seconds for uranium radionuclides, with acceptable surface levels of <5000 dpm/100 cm^2 is statistically sound.

9. Enter the command 'F30' or 'F60' to set the count time and then enter the command 'C' to start the counts. Save the readings in either the Model 2350's memory, the computer program/database, or record on the calibration form.

10. Repeat the above procedure 8-10 times and take an average.

11. Subtract the average background rate determined earlier from the calibration source counts.

12. Calculate the response efficiency by dividing the average detector counts (corrected by subtracting out the background level) by the actual calibrated source level and then multiplying this value by 100. This is the detectors counting efficiency.

13. The minimum detectable activity (MDA) can then be calculated by using the following formula:

$$MDA = \frac{2.71 + (4.66\sqrt{B})}{TxExG}$$

MDA	=	activity level in dpm/100 cm^2
B	=	background (total counts)
T	=	count time to be used for field measurements (minutes)
E	=	operating efficiency (counts/disintegration)
G	=	detector geometry (detector area cm^2/100)

14. The MDA is compared to the site guideline value and should be less than 50% of the applicable criteria for the site. NOTE: The MDA is the 95% confidence value (i.e., confidence of neither having a false positive nor a false negative result).

15. Position an alpha check source at the detector and count for one minute by entering the command 'C'. Reposition the source and detector and repeat count 8-10 times. Calculate the average value and the 3 sigma value for the samples. The 3-sigma value should be <10% of the mean. If it is not, then the instrument/detector must be removed for service before operation.

16. The same check source will need to be taken to the site with the calibrated instrument.

17. An instrumental operational check-out form should be prepared.

18. Daily instrument operational check-outs should be performed according to the calibration procedure outlined in the Survey SOPs.

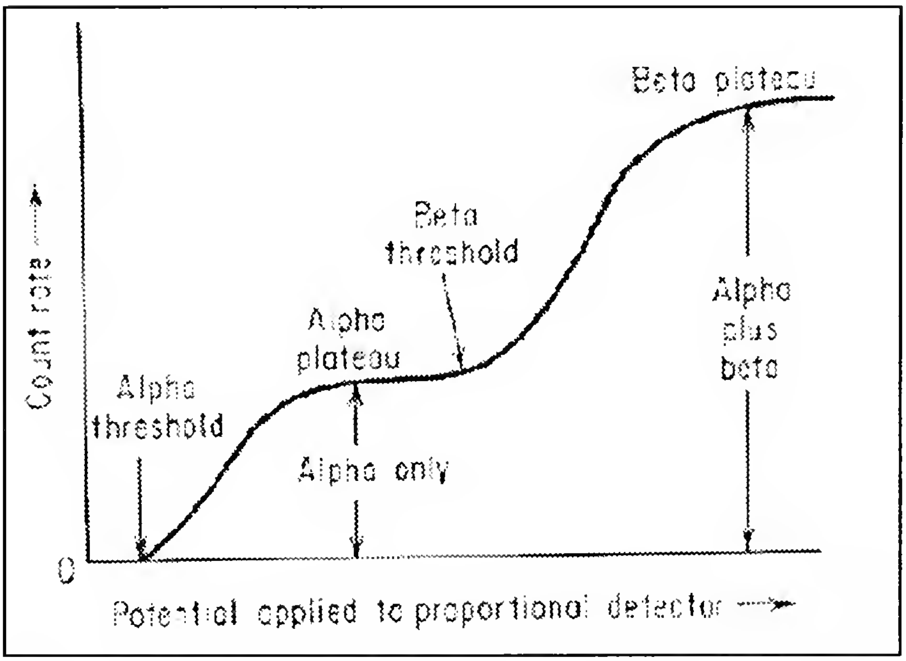


Figure C-2. Alpha and beta plateau curve (from Wang et al., 1975).

CALIBRATION DATA - - ALPHA/BETA

SITE_________________

Instrument Type ____________________ Calibration Source___________________
Detector Type_______________________ Purge Check________________________

Source Disintegration Rate (dpm)	Gross Instrument Count Rate (cpm)	Net Instrument Count Rate (cpm)	Efficiency (cpm/dpm)	Check Source Reproducibility Test

High Voltage _____________Threshold_______________ Window ________
Check Source radionuclide and ID# __________________________________
Position of Check Source ______________
Average Background_______________________ Check Source Range ___________

Date______________ Calibrated By_____________________________

Figure C-3. Calibration form.

Calibration and Operational Check-Out of a GM Detector

I. Purpose:

To describe the procedures for calibration and operational check-out of survey GM detectors to be used with the Ludlum Model 2350 or comparable ratemeter.

II. Responsibilities:

1. The site coordinator or health and safety officer is responsible for the proper procedural implementation.

2. The survey team is responsible for procedural adherence.

III. Equipment:

1. Ludlum Model 2350 Ratemeter/Datalogger or comparable device.
2. GM detector capable of interfacing to the Model 2350.
3. Necessary cables and connections.
4. Record forms and/or computer database.
5. Calibration sources.
6. Check sources.

IV. Procedure:

1. Attach the GM detector with the cable to the Model 2350 and turn on the device.

2. Set the threshold to 50 by entering the command 'T50' through the terminal or computer keyboard.

3. Set the high voltage to 900 volts.

4. Take 8-10 background readings by counting for 60 seconds each. Calculate the average and the 3-sigma values from the data and record or save in the database.

5. Use a calibrated beta source and count for 60 seconds or until approximately 10,000 gross counts are accumulated.

6. Repeat this count four additional times and determine the mean.

7. Subtract the mean background counts from the mean gross counts to get the mean net counts. Record this value on the calibration form.

8. Determine the detector efficiency to the nearest two significant digits by dividing the mean net counts by the calibrated beta source activity (make sure the conversions from micro-curies or Becquerel are made to dpm).

9. Calculate the minimum detectable activity (MDA) using the following formula:

$$MDA = \frac{2.71 + (4.66\sqrt{B})}{TxExG}$$

MDA	=	activity level in dpm/100 cm^2
B	=	background in total counts
T	=	count time in minutes to be used in the field measurements
E	=	operating efficiency in counts per disintegration
G	=	detector geometry in area in cm^2 per 100)

10. The calculated MDA is then compared to the site criteria and should be less than 50% of this value. If it meets this criteria, then it can be assumed that the instrument has adequate sensitivity for field use.

11. Position the beta check source on the detector and accumulate the count for 60 seconds. Record the count rate and time.

12. Reposition and repeat the count 10 times.

13. Calculate the mean and 3-sigma values.

14. If the 3-sigma value is less than 10% of the mean, then the detector is reliable enough for field use. If it exceeds the 10% criteria, then the detector must be removed from service and repaired.

15. An Operational Check-Out Form and the original check source is to accompany the survey team to the site.

16. Daily instrument check-outs should be performed according the calibration outline given in the Survey Standard Operating Procedures.

Calibration of the Field Measuring Tape for Positioning Quality Assurance

I. Purpose:

To describe the procedures for maintaining a traceable, standardized measuring tape for field automatic positioning calibration procedures. The field survey tape will then be used as the standard for the calibration of the automatic positioning techniques.

II. Responsibilities:

1. The site coordinator or survey team leader is responsible for maintaining custody of the standard calibration tape and for assuring procedural implementation.

2. The survey technicians are responsible for following the outlined procedures.

III. Equipment:

1. INVAR standard measuring tape.
2. Field survey tape.
3. Calibration form.
4. An appropriate anchoring point (e.g., survey stake, chaining pin, etc..).

IV. Calibration Procedure:

1. Obtain the INVAR Standard Tape from the appropriate source.

2. Attach the INVAR Standard Tape and the field survey tape to a common anchor point such that the starting point is aligned to the zero point on the INVAR tape.

3. While holding the tapes adjacent, stretch the field survey tape.

4. Using a tape calibration form, record the distance intervals for the field tape and INVAR standard at intervals of 1%, 5%, 10%, 25%, 50%, 75%, and 100% of the full tape length.

5. Compare the field survey tape results and the INVAR measurement results to assure that all points meet the +/- 1 % criteria.

6. If the points are in specification, file the form and return the INVAR Standard tape clean to the appropriate storage location.

7. If the results do not meet criterion, mark the tape as unacceptable.

8. The acceptable tape should be used in the calibration procedure for the automatic positioning procedures. In addition, the calibrated tape will be used as a means of quality control and quality assurance during the Survey Standard Operation Procedures. Thus, the calibrated tape should accompany the team to the site.

Operational Check-Out and Calibration of the Serial Mouse

I. Purpose:

To describe the procedures for operationally checking out and calibrating the serial mouse that will be used to automatically position the survey sample taken.

II. Responsibilities:

1. The site coordinator is responsible for procedural implementation.

2. The survey technicians are responsible for the actual check-out and calibration.

III. Equipment:

1. Compatible serial mouse or track ball assembly.
2. NIST traceable field calibration tape.
3. Appropriate cables and connections.
4. A serial multiplexer.
5. A notebook computer with serial port.
6. Marking tape.

IV. Procedure:

1. The serial mouse should be operationally checked-out prior to calibration. The roller ball should be cleaned and the contacts should be adjusted and cleaned.

2. Attach the serial mouse to the computer via its serial port.

3. Choose the proper switch alignment on the multiplexer and check all cable connections.

4. Turn on the computer and check for proper battery charge.

5. Configure the serial mouse to the computer.

6. Enter the Serial Mouse Counts computer program from the Visual Basic program menu. This program supplies the number of binary counts generated by the relative movement of the serial mouse and can be used for calibration curve generation.

7. A point of reference is established at one of the four corners of the mouse assembly. Fix the beginning of the calibrated field tape and the mouse at the reference corner.

8. With the counts generated by the mouse and represented by the computer program, move the mouse in a straight line. A straight edge would be helpful to keep the alignment optimal.

9. At distances of 6 inches, 12 inches, and 18 inches, the readings from the computer program are evaluated and recorded. This procedure is performed in each of the four mutually orthogonal directions.

10. From these results, calibration equations are established and recorded.

11. Calibration curves are generated and further distance comparisons are extrapolated.

12. The four calibration equations are then entered into the main system computer protocol as code algorithms.

Operational Check-Out and Calibration of the Ultrasonic Rangefinder

I. Purpose:

To provide a procedure for operationally checking out and calibrating an ultrasonic positioning system that can be used to provide automated spatial data for the site survey.

II. Responsibilities:

1. The site coordinator is responsible for the procedural implementation.

2. The survey technicians are responsible for following the procedural guidelines.

III. Equipment:

1. Polaroid Ultrasonic Ranging Developer's Kit or comparable unit.
2. NIST traceable field calibration tape.
3. Shielded circuit board assembly.
4. Necessary wires, cables, and connectors.
5. Regulated DC power supply.
6. PCMCIA Data acquisition card.
7. Visual Basic programming software.
8. Notebook computer with Type II PCMCIA slot.
9. Marking tape.
10. Oscilloscope.
11. Multimeter.

IV. Procedure:

Operational Check-Out

1. The ultrasonic circuit board (supplied with the kit) should be placed inside a shielded box and the power supply should be connected to Pin 1 and Pin 2 (ground) and tested for proper working function. The power supply should be set at 12VDC. Turn off the power supply.

2. The Piezo transducer should be connected between Pin 14 and Pin 13 on the circuit board. This can be done with some lighter gage wire.

3. Set the transducer switch S2 on the circuit board to the 'Up' position.

4. Connect Pin 4 (analog output) on the board to Pin 1 on the data acquisition card terminal strip and connect Pin 7 (ground) to Pin 3 on the data acquisition card terminal strip.

5. Turn on the power supply to the ultrasonic board.

6. Turn on the computer.

7. Turn on the circuit board.

8. Operation of the circuit board can be determined by whether or not the LED indicator on the board lights up and displays a distance measurement. If it does, the operational check out of the hardware is complete.

9. Check system configuration and interface by selecting from the Windows Menu the NI-DAQ 4.5.1 program icon and running the Visual Basic AIAO program. Test by executing several "voltage reads" while moving the transducer incrementally. If this procedure checks out, then the unit is configured and all of the proper interfaces and connections have been made.

10. The actual rangefinder calibration can be performed from within this NI-DAQ 4.5.1 program or from within the Environmental Survey System software (the preferred method).

11. If within the Environmental Survey System program, the user first needs to select the site or calibration menu item to identify the procedure.

12. The user next chooses the method of positioning (ultrasonic), and then bypasses the configuration and background screens.

13. The user now enters the main survey screen and begins the process of calibration.

General Rangefinder Calibration Procedure

1. Determine the range of calibration. It is recommended that the ultrasonic not be calibrated for ranges greater than 10 meters.

2. Attach the calibrated field survey tape to an anchor at the same location as the Piezo transducer. This will set the reference (0,0).

3. Determine the actual maximum distance by measuring from the (0,0) reference to the final surface with the calibrated survey tape. Record this distance in the box location marked "North-South Traverse" on the computer screen.

4. Proceed by moving in a straight fashion, parallel to the survey tape, with the ultrasonic transmitting to the flat, "north" surface (e.g., wall, survey plate) at the predetermined range.

5. Stop and take readings and log readings at intervals of 5% increments. Thus, if the range is 10 meters, the readings would be taken at 0.50 meter increments (i.e., at 0.00, 0.50, 1.00, 1.50, ... 9.50, and 10.00).

6. Compare the readings taken at the locations on the calibrated field survey tape with the ones automatically taken by the ultrasonic transducer. All of the points should satisfy a +/- 0.5% accuracy criterion.

7. If this criteria has been met, the ultrasonic rangefinder is calibrated and ready for field implementation.

8. If this criteria has not been met, the ultrasonic board may need to be calibrated by adjusting the R22 gain control potentiometer to determine the correct set point.

9. Repeat Steps 2-6 after each clockwise or counter-clockwise adjustment of R22.

Electronic Rangefinder Calibration Procedure (Fine Tuning)

1. In order to meet the +/-0.5% criterion, it may be necessary to adjust the circuit board. Begin by finding a LC circuit with the components of L1 and C17.

2. The value for C17 (between 0.96mh and 1.13mh will be dependent upon the transmit frequency of the transducer.

3. Adjust the value for C17 based upon the criteria given in the Polaroid Ultrasonic Ranging Developer's Kit Manual.

4. If the unit still does not meet the specification after fine tuning for the transmit frequency, it may be necessary to change the peak amplitude of the drive voltage or to alter the overall gain. Please refer to the Polaroid Ultrasonic Ranging Developer's Kit Manual for these procedures.

5. If after completing both the general calibration procedure and the electronic calibration procedure and there are still problems meeting the criteria, make sure that the board is properly shielded from the notebook.

6. It is possible to adjust R21 on the board to a threshold which will exceed the level of noise radiation from the notebook. Thus, turn R21 clockwise to determine if this eliminates erroneous measurement results.

7. If after following the above procedures and still the problem is evident, call the manufacturer for assistance.

APPENDIX D
GENERAL SITE SURVEY STANDARD OPERATING PROCEDURES

I. Purpose:

To provide a method for performing automated indoor radiological surveys. The following procedures can be applied to alpha, beta, gamma, and surface scans. However, specific operating procedures are given for each.

II. Responsibilities:

1. The site coordinator is responsible for procedural implementation.

2. The survey team personnel are responsible for procedural compliance.

III. Equipment:

1. Mobile Survey Apparatus with mechanical distance counters.
2. Ludlum Model 2350 Ratemeter/Datalogger or comparable instrument.
3. Compatible alpha/beta and gamma radiation detectors (e.g., Ludlum Model 43-89 Alpha/Beta Scintillator, Ludlum Model 44-10 Gamma Detector, or comparable).
4. Notebook computer with serial, parallel, and Type II PCMCIA slots.
5. PCMCIA data acquisition card (e.g., NI-DAQ 700 or comparable).
6. Ultrasonic rangefinder assembly with Piezo transducer and adjustable 90 degree mount and shielded box.
7. Serial computer mouse.
8. Laser pointer.
9. Two-position serial multiplexer.
10. Necessary cable and connectors (e.g., RS-232, 9-Pin-to-16 Pin adapters)
11. Calibrated check source (similar to the contaminant on-site).
12. Calibrated field measuring tape.
13. QC marking tape.
14. Environmental Survey software (written in Visual Basic)
15. Microsoft Access and Excel database and spreadsheet software.
16. Wiring manifold or connection block.

IV. Procedure:

A. Preliminary Survey Site Evaluation

1. Upon arrival at the site, the rooms of interest should be cleared of all obstacles.

2. The calibrated field measuring tape should be used to take a north-south and east-west transect of the room, identifying all walls of concern.

3. If possible, a hand or computer sketch of the room could be made as a quality control check.

4. From the room dimensions, determine the number of one meter by one meter survey units that exist. In your determination, make sure to come in approximately 0.5 meters from each of the walls to allow for survey apparatus size constraints (i.e., the zero-zero reference will be located approximately 0.5 meters in from both perpendicular walls).

B. System Set-Up

1. Unload all system hardware.

2. An operational check-out of all components should be made again on-site. These procedures are outlined in Appendix B but include primarily checks on battery voltages and connections.

3. Zero out the mechanical distance counters on the wheels of the survey apparatus.

4. Turn on the Ludlum 2350 Ratemeter/Datalogger with the appropriate detector attached.

5. Use the calibrated check source to determine a detector efficiency. The mean from a sample size of five counts of one minute each should provide a value of counts with more than adequate statistical confidence. Divide this mean by the calibrated source's activity and multiply by 100 to get the detector efficiency. Compare with the value with the off-site determined efficiency. These values should not vary by more than +/-2%, figured at one significant digit beyond the decimal point. If there is a significant discrepancy, repeat the procedure.

6. Turn on the computer.

7. Enter Visual Basic from Windows.

8. Choose 'Environmental Survey' from the File menu icon.

9. After the survey forms are represented, choose 'Start' from the Run menu option.

10. Choose 'Site Information' from the File menu option and enter all pertinent data. Following this procedure will develop the necessary link to the Microsoft Access database and will be automatically saved.

11. Exit back to the main screen and choose 'Select Instruments' from the Survey menu icon.

12. Select the appropriate positioning device (Trackball or Ultrasonic) and survey instrument (Ludlum 2350) from the list of options. Exit back to main screen.

13. Select 'Site to Survey" from the Survey menu item. The site was identified during Step 10 above.

14. Select 'Begin Survey' from the Survey menu item.

15. The main survey form will come up.

16. Choose 'Configure Ludlum' from the Command menu item.

17. Enter the pertinent information to configure the Ludlum Model 2350 (i.e., efficiency, threshold, high voltage, scale, units, detectors, etc...) and accept values. Exit back to the main screen.

18. From the Command menu, choose 'Take Background' and take 8-10 background readings (default=9) from adjacent rooms and from areas surrounding the site. The average background reading and the minimum detectable activity will be automatically calculated after the background counter box reaches zero. Exit the background screen and return to main survey form.

19. See specific standard operating procedures for alpha, beta, and gamma surveys for details on the program progression of the survey beyond this point.

C. Survey Traverse Techniques (General)

1. For the floor survey, position the total calibrated survey apparatus at the (0,0) reference point. Preferably, the choice of this location should be in the southwest corner of the room at a distance of 0.5 meters from the south wall and 0.5 meters from the west wall. This allows enough room for the survey apparatus to maneuver.

2. If the method of positioning will be ultrasonic ranging, then the north-south room transect and the east-west room transect must be entered either manually from the field tape value. This will establish a "true" zero reference for quality assurance, accuracy, and repeatability checks. The (0,0) reference should be marked with tape.

3. The necessary algorithms have been entered into the program that rely specifically on the walls the signals are being transmitted to. Thus, for the ultrasonic positioning technique, the two perpendicular walls that the ultrasonic is "aimed" at must be identified on the main program form.

4. If the mouse-traverse positioning technique will be used instead, then the (0,0) reference for the survey will be set at true (0.5,0.5). In essence, the same physical location will be used as that for the ultrasonic positioning technique. The mouse-traverse will be zeroed at this point.

5. No matter which positioning technique is implemented, the survey traverse is begun by moving in a straight line from one end of a survey unit to the next, taking and logging readings of both space and magnitude. Since the survey units are only one meter by one meter squares, then only three readings will be taken along the first straight movement; in essence, at (0.00, 0.00), (0.00, 0.50), and (0.00, 1.00).

6. The survey apparatus is now turned 90 degrees, keeping the proper orientation on the trackball or the ultrasonic assembly, and stopped at location (0.50, 1.00) for the next reading of both space and magnitude. This traverse is continued until nine points, which equals one total survey unit, have been taken.

7. This procedure is repeated for all of the floor survey units identified.

8. Figure D-1 illustrates the concept of survey unit. For further clarification of the survey traverse technique, please see Figure D-2.

9. It is necessary to survey the walls of the room (usually up to two meters). The same apparatus can be used to automatically survey the walls. However, the positioning assemblies must be removed from the survey apparatus and "rolled" along the wall. If the ultrasonic rangefinder is to be used, then it will be necessary to take reading from the floor and ceiling, and thus, some minor program protocol changes must be made.

10. It is also necessary to survey the ceiling and above the ceiling tiles for contamination. The automated technique, as currently designed cannot be used in its entirety. However, the Ludlum Model 2350 with hand-held terminal can be used to take readings at these locations. The data can then be downloaded to the computer program for analysis.

11. See the specific standard operating procedures for alpha, beta, and gamma surveys for more details on the traverse progression of the survey beyond this point.

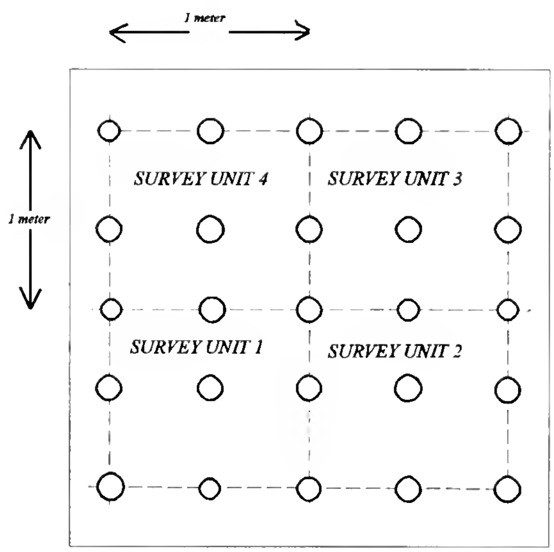


Figure D-1. Survey units with 9 sampling points per unit.

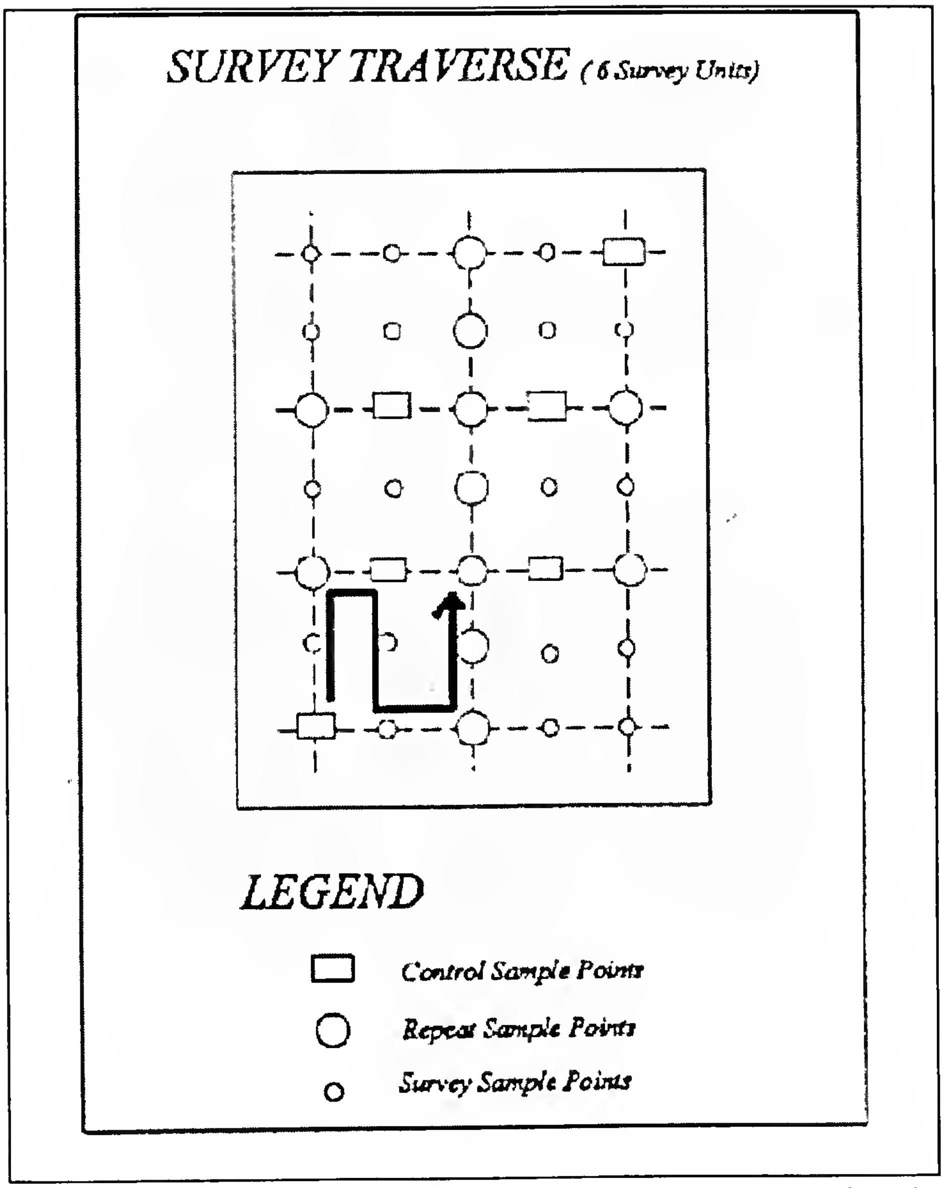


Figure D-2. General survey traverse showing control, repeat, and total sampling locations.

Automated Indoor Alpha Survey Procedures

I. Purpose:

To describe the method for automatically positioning and determining site alpha radiation levels on building surfaces at indoor sites.

II. Responsibilities:

1. The implementation of the procedure is the responsibility of the site coordinator.

2. The survey technician is responsible for following the outlined procedure.

III. Equipment:

1. Mobile Survey Apparatus with mechanical distance counters.
2. Ludlum Model 2350 Ratemeter/Datalogger or comparable instrument.
3. Alpha radiation detector comparable to the Ludlum Model 43-89 Alpha/Beta Scintillator.
4. Notebook computer with serial, parallel, and Type II PCMCIA card slots.
5. PCMCIA data acquisition card.
6. Ultrasonic rangefinder assembly with Piezo transducer and adjustable 90 degree mount and field shielded box.
7. Durable serial computer mouse or trackball.
8. Laser pointer.
9. Two-position serial multiplexer.
10. Necessary cables, wires, and connectors (e.g., RS-2323, 9-to-16 Pin adapters, etc..).
11. Calibrated alpha check source (preferably, the radionuclide on-site).
12. Calibrated field measuring tape.
13. QC marking tape (e.g., duct tape).
14. Environmental Survey software (written in Visual Basic).
15. Wiring manifold/connection block.

IV. Procedure:

A. Alpha Survey with Ultrasonic Positioning

1. Following all of the procedures outlined under the General Site Survey Standard Operating Procedures, operationally check-out and set-up the total survey system. NOTE: The appropriate counting time is usually set at 60 seconds for most radionuclides and will be entered during the Ludlum configuration along with the efficiency, threshold, and high voltage values.

2. Assemble the detector/instrument unit by attaching the Ludlum Model 43-89 detector to the Ludlum 2350.

3. Turn on the Ludlum 2350 and check battery voltage and, by using the hand-held terminal, enter some lines of code (from the Ludlum Operations Manual) to make sure the unit is operating.

4. Turn on all other instrumentation and check for battery voltages, proper connections, and general operational parameters.

5. After check-out and set-up has been successfully completed, temporarily disconnect the detector instrument from the rest of the system and determine the detector efficiency by taking counts of alpha radiation disintegrations from the calibrated check source, preferably of the same alpha emitter expected to be found on-site.

6. Place the detector's face on the surface of the calibrated check source.

7. The default readings stored in the Ludlum 2350 from the configuration step should have a count time of 60 seconds. The hand-held terminal can be used to enter the command 'C' to start the count (See Ludlum Operations Manual if necessary).

8. At the completion of the count time , record the number of counts.

9. Repeat this procedure four more times and determine the mean from the five count values. Divide this mean by the calibrated source's activity and multiply by 100. This will give you the site and detector efficiency. This value for efficiency should be within +/- 1% the efficiency value found during the original calibration. If it is not, repeat the process.

10. If the value varies by greater than +/- 1%, then the Ludlum 2350 will need to be reconfigured with a new value for the efficiency entered into the proper box. A good value for this efficiency would be the mean of the lab calibrated mean and field calibrated mean.

11. After the technician has went through the program set-up, outlined under the General Site Survey Operating Procedures (e.g., background, configuration, etc..), the main survey screen will be represented. Make sure that the high voltage and threshold values entered are based upon calibration data.

12. Position the total apparatus in the southwest corner of the room, facing the north wall/surface.

13. Begin the transect of the defined survey units by following the procedures outlined in Survey Transect Procedure (General).

14. The transect begins at the (0,0) reference point, with the main computer form up. While the following procedures can be applied to wall surveys, they will be presented for a floor alpha survey.

15. If the ultrasonic positioning technique is employed, the assembly must first be positioned facing the north wall and indicated on the main screen by selecting the north wall option block. It is best, if at all possible, to take measurements from the same walls. This will avoid technique confusion.

16. Hold the laser pointer next to the transducer and transmit the light to the surface the transducer is pointing toward. This is a quality control check that assures that the transducer is actually transmitting to the surface of choice.
NOTE: It is not recommended to use ultrasonic positioning to determine ranges greater than 10 meters. If the rooms are larger than this, accommodations must be made to provide survey tripods with flat surfaces to obtain accurate distances.

17. Once the transducer is aligned and transmitting properly, a reading is taken and logged by entering the proper commands from the Command menu item.

18. The ultrasonic assembly is then rotated 90 degrees clockwise and the same procedure is followed.

19. Place the 100 square centimeter detector face at the location of the first reading. In addition, place a piece of tape on the floor at the center point of the detector face. This tape will be used as a reference location for process quality control and as a method of control point designation.

20. Choose 'Take Reading' from the Command menu. The Ludlum Model 2350 will start to count down from the configured count time (e.g., 60 seconds) and give a total counts per unit time.

21. Enter 'Log Reading' from the Command menu. The program will calculate and represent the net cpm and net dpm for the sample. In addition, the program's spreadsheet will give the value for width (x), length (y), gross dpm for the sample.

22. Continue the survey traverse by moving to location (0.00, 0.50) and following the same procedure as outlined above.

23. Complete Survey Unit #1 by moving in the fashion as illustrated by Figure D-2. At the completion of the ninth sample, hit enter one more time and the program will calculate and represent the average value for the survey unit as well as the 95% confidence value. NOTE: For samples with counts less than the MDA, the MDA value will be represented instead of the sampled value.

24. Follow the above procedure for the total number of survey units. Figure D-2 indicates a six survey unit traverse. Notice, for quality assurance purposes, there are repeated sampling points along the progression of the survey.

25. The repeat sampling points (i.e., the large circle sampling locations on Figure D-2) are locations where the activity measurements are repeated. The values will be used for activity measurement comparisons on repeatability.

26. The control sampling locations (i.e., rectangular box sampling locations in Figure D-2) are used for spatial repeatability and accuracy comparisons. A piece of duct tape, placed on the floor at the center of the detector face, should be used to mark each of these locations.

27. Check the accuracy of the positioning system by measuring the location of the control points with the calibrated measuring tape.

28. The computer calculation of the survey unit average levels and 95% confidence levels are then compared to site guidelines values.

29. If the average or maximum values are exceeded, decontamination will be necessary of the survey unit area until the levels meet the site criteria.

30. After the completion of the total survey traverse, choose View Data or Print Report from the File menu. The data has been automatically saved in the system database.

31. Choose Exit from the File menu.

32. Perform quality control measurement analyses on both spatial data (control points) and magnitude data (repeat points).

33. Link database to Excel and Stanford Graphics (or comparable programs) to get a 3-D representation of the room profile.

34. Complete any necessary report forms.

B. Alpha Survey with Mouse Traverse Positioning

1. Follow all of the same procedures as those for ultrasonic positioning except:

   a. The determination of the north-south traverse and east-west traverse is not necessary and is not a screen option.

   b. The mouse assembly must stay orientated at all times in the forward direction. Thus, the mount assembly must be moved at 90 degree turns while keeping the mouse in a "fixed" position.

   c. A choice of direction (i.e., north south, east, west) is not necessary, and thus, is not provided on the main screen.

   d. Since the mouse shares the one computer serial port with the Ludlum Model 2350, it must be engaged when taking a measurement and disengaged while the Ludlum 2350 takes a count. This is accomplished through the screen choices 'Engage Mouse' and 'Disengage Mouse'. In addition,

mechanical adjustments must be made by switching the multiplexer (data selector) from the mouse-connect side to the Ludlum-connect side.

e. Proper care should be taken when the mouse-traverse method is to be used on rough surfaces. NOTE: The mouse-traverse method is not recommended for use on floors other than tile or a similar material.

Automated Indoor Gamma Survey Procedures

I. Purpose:

To describe the technique for performing the automated gamma survey for indoor sites.

II. Responsibilities:

1. The procedural implementation is the responsibility of the site coordinator.

2. The survey technician is responsible for following the procedure.

III. Equipment:

1. Mobile Survey Apparatus with mechanical distance counters and gamma detector mount at one meter from the floor.
2. Ludlum Model 2350 Ratemeter/Datalogger or comparable instrument.
3. Sodium Iodine Scintillator comparable to the Ludlum Model 44-10 High Energy Gamma Detector.
4. Notebook computer with serial, parallel, and Type II PCMCIA card slots.
5. PCMCIA data acquisition card.
6. Ultrasonic rangefinder assembly with Piezo transducer and adjustable 90 degree mount and field shielded box.
7. Durable serial computer mouse or trackball.
8. Laser pointer.
9. Two-position serial multiplexer.
10. Necessary cables, wires, and connectors (e.g., RS-2323, 9-to-16 Pin adapters, etc..).
11. Calibrated gamma check source (preferably, the radionuclide on-site).
12. Calibrated field measuring tape.
13. QC marking tape (e.g., duct tape).
14. Environmental Survey software (written in Visual Basic).
15. Wiring manifold/connection block.

IV. Procedure:

A. Operational Check-Out

1. Connect the gamma detector to the Ludlum Model 2350, adjust the high voltage as necessary per calibration (e.g., 950 for Cs-137), and set the Model 2350 to the 'Slow' response.

2. Follow the configuration procedure outlined in the Ludlum 2350 Operation Manual to set-up the gamma scintillator.

3. Check the background count rate and the detector response to the gamma check source by entering the command 'C' from the hand-held terminal. The unit should be removed from service if the check source response is determined to be outside the limits.

4. Refer to procedures outlined under Calibration and Check-Out of a Gamma Scintillation Detector for further clarification.

B. Apparatus Set-Up

1. Insert the gamma scintillation detector through the hole in the mounting assembly.

2. Adjust the thumb screws to provide for a level seating of the detector. The calibrated field measuring tape should be used to adjust the detector until its bottom face is one meter from the floor. NOTE: For wall or ceiling measurements, the mounting assembly will not be used and each sampling must be measured manually.

3. Run the cable from the detector, through the top of the detector mounting assembly, and connect to the Ludlum Model 2350

4. Follow the same set-up procedures as for those outlined in the Automated Indoor Alpha Survey Procedures and General Procedures except for:

   a. During the Ludlum 2350 configuration, enter the units of micro-R/hour instead of counts per minute.

   b. Move to a sampling location and wait for about five seconds and then 'Take' and 'Log' (choose from the

Command menu) the exposure readings. These readings are estimated average count rates for the regions of concern rather than the "absolute" reading obtained by an alpha or beta measurement.

5. Follow the same survey traverse procedures as outlined under General Site Survey Standard Operating Procedures and under the Procedure section of Automated Indoor Alpha Survey Procedures.

Automated Indoor Beta Survey Procedures

I. Purpose:

To describe an automated technique for determining the location and level of beta radiation on indoor surfaces.

II. Responsibility:

1. The procedural implementation is the responsibility of the site coordinator.

2. The survey technician is responsible for following the approved procedure.

III. Equipment:

1. Mobile Survey Apparatus with mechanical distance counters.
2. Ludlum Model 2350 Ratemeter/Datalogger or comparable radiological instrumentation.
3. Beta radiation detector comparable to the Ludlum Model 43-89 Alpha/Beta Scintillator or a GM "Pancake".
4. Notebook computer with serial, parallel, and Type II PCMCIA card slots.
5. PCMCIA data acquisition card.
6. Ultrasonic rangefinder assembly with Piezo transducer and adjustable 90 degree mount and field shielded box.
7. Durable serial computer mouse or trackball.
8. Laser pointer.
9. Two-position serial multiplexer.
10. Necessary cables, wires, and connectors (e.g., RS-2323, 9-to-16 Pin adapters, etc..).
11. Calibrated beta check source (preferably, the radionuclide on-site).
12. Calibrated field measuring tape.
13. QC marking tape (e.g., duct tape).
14. Environmental Survey software (written in Visual Basic).
15. Wiring manifold/connection block.
16. Alpha shield - approximately 5 micron thickness (if required).

IV. Procedure:

1. Follow the same procedures as those outlined under General Site Survey Procedures and Automated Indoor Alpha Survey Procedures except for:

    a. The use of an alpha shield for certain detectors will need to be utilized to discriminate between the alpha and beta radiations. See the data on the specific beta detector for details.

    b. The use of beta parameters for calibration, efficiency, high voltage, threshold, etc.. instead of those given for the alpha detector.

2. The Ludlum 2350 Operations Manual should be referred to for further clarification on operational check-out, calibration, and command routines.

APPENDIX E
EXAMPLE MANUAL SURVEY FORMS

AREA SCAN AND RADIATION LEVEL SURVEY

SITE ______________________ INSTRUMENT ______________________

DATE/TIME ______________________ PROBE ______________________

SURVEYOR(S) ______________________ ______________________

GRID POINT

GRID POINT

SCALE:
1/2" = ________

REFERENCE DIRECTION

GRID POINT

GRID POINT

AVERAGE OR RANGE OF LEVELS: ______________________

ELEVATED READING			ELEVATED READING		
GRID LOCATION	cpm	$\mu R/hr$	GRID LOCATION	cpm	$\mu R/hr$

REMARKS: ______________________

CALCULATIONS BY: ______________________ REVIEWED BY: ______________________

DATE: ______________________ DATE: ______________________

FORM14a(11-93)

Figure E-1. Area scan survey form.

SURFACE ACTIVITY SURVEY

SITE ______________________

AREA ______________________

DATE/TIME ______________________

SURVEYOR(S) ______________________

	INSTRUMENT	PROBE	BACK-GROUND	EFFI-CIENCY	MDA dpm/100cm2
ALPHA					
BETA					
GAMMA					

GRID POINT

FLOOR

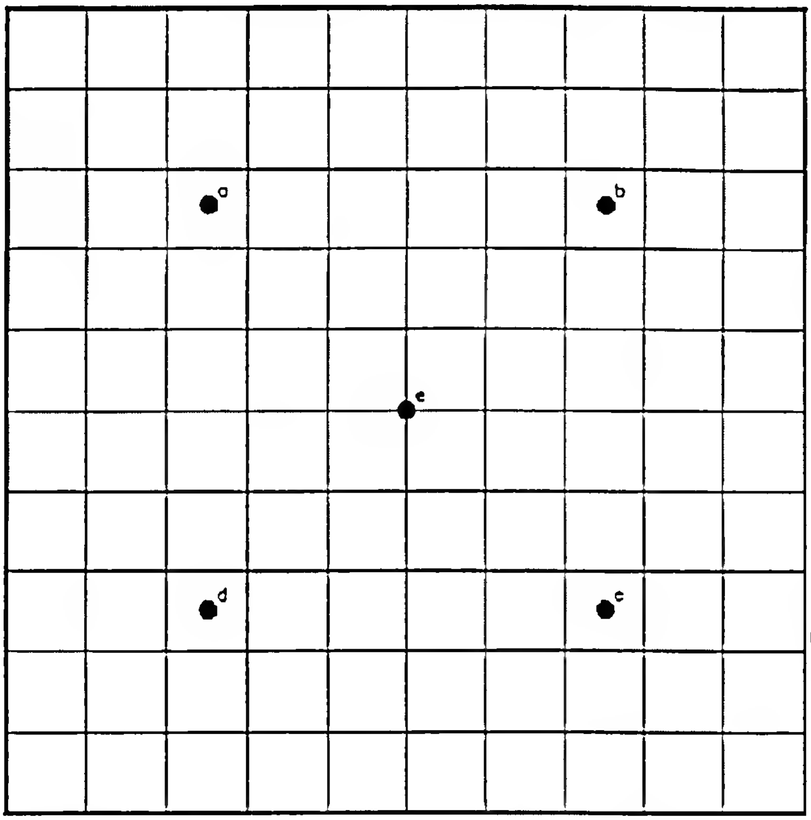
LOWER WALL

UPPER WALL

CEILING

OTHER _____

GRID POINT



GRID POINT

REFERENCE DIRECTION

SCALE:

1/2" = ________

GRID POINT

SCAN RANGE: α ____________ β ____________ γ ____________

LOCATION	DIRECT PROBE MEASUREMENTS				REMOVABLE CONTAMINATION (Smears)		
	ALPHA		BETA-GAMMA			ALPHA	BETA
	c/___m	d/m/100cm2	c/___m	d/m/100cm2	SMEAR #	dpm/100cm2	dpm/100cm2
A							
B							
C							
D							
E							
AVERAGE							

REMARKS: ______________________

CALCULATIONS BY: ______________________ REVIEWED BY: ______________________

DATE: ______________________ DATE: ______________________ FORM19(11-93)

Figure E-2. Sample of surface activity survey form.

ACTIVITY SURVEY RECORD

SITE ______________
AREA ______________
START TIME: ________ END TIME: ________
DATE ______________
SURVEYOR(S) ______________

TYPE	INSTRUMENT	DETECTOR	BKG. (cpm)	EFF.	MDA dpm/100cm2

LOCATION	DIRECT DETECTOR MEASUREMENTS				REMOVABLE ACTIVITY			REMARKS
	TYPE:		TYPE:			ALPHA	BETA	
	c/___m	dpm/100cm²	c/___m	dpm/100cm²	SMEAR #	dpm/100cm²	dpm/100cm²	

CALCULATIONS BY: ______________ DATE: ______________ ☐ DATA REVIEWED ☐ CALCULATIONS REVIEWED FORM35(11-9

Figure E-3. Example activity survey record form.

REFERENCES

Aeschlimann, H. and Stocker, R., *Instrumental Errors in Electro-Optical Distance Measurements,* paper presented at the Proceedings of 14th FIG Congress, Washington, DC, 1974.

ANSI N323, *Radiation Protection Instrumentation Test and Calibration*, Institute of Electrical and Electronic Engineers, Inc., September 1978.

Bateson, R., Introduction to Control System Technology. Merrill, 1973.

Berger, J.D., *Manual for Conducting Radiological Surveys in Support of License Termination*, Oak Ridge Associated Universities, NUREG/CR-5489, ORAU-92/C57, 1992.

Berven, B.A. Little, C.A., and Blair, M.S., A *Method to Automated Radiological Surveys: The Ultrasonic Ranging and Data System*, Health Physics, 60(3), 367-373, 1991.

Blitz, J., Ultrasonics: Methods and Applications. Van Nostrand Reinhold, 1971.

Bogart, T.F., Introduction to Digital Circuits. Glencoe, 1991.

Bolch, W.E., *A Plan for the Termination of the Radioactive Materials License No. 396.3 for the Uranium Recovery Operation at Riverview, Florida Held by Cargill Fertilizer, Inc.*, University of Florida and Quadrex Environmental, 1992.

Bolch, W.E., Napier, R.R., and Warren, B.C., *Radiological Survey Results for the Uranium Recovery Operation of Gardinier, Inc., Riverview Florida*, Quadrex Environmental, 1991.

Brinker, R.C., and Minnick R., The Surveying Handbook. Van Nostrand Reinhold, 1987.

Broch, J.T., Acoustic Noise Measurements. Bruel & Kjaer, 1973.

Burkart, J.A., Eggenberger, L.M., Nelson, J.H., and Nicholson, P.R., *A Practical Statistical Quality Control Scheme for the Industrial Hygiene Chemistry Laboratory*, American Industrial Hygiene Association Journal, 45(6), 386-392 , 1984.

Carter, J., *Digital Representations of Topographical Surfaces,* Photogrammetric Engineering and Remote Sensing, 39(11), 1577-1582, 1988.

Cember, H., Introduction to Health Physics. Pergamon Press, 1989.

Chemrad, USRADS Technical Bulletin on the USRADS Series 2100, Oak Ridge, TN, 1992.

Chemrad, INRADS 2D Technical Proposal, Oak Ridge, TN, 1994.

Collins, J., *GPS Surveying Techniques,* Point of Beginning, 11(4), 22-24, 1987.

Cooper, M.A., Control Surveys in Engineering. Collins, 1987.

Craig, C.C., *The X-bar and R-Chart and Its Competitors*, Journal of Quality Technology. 1(2), 102-104, 1969.

Crosswell, P. and Clark, S., *Trends in Automated Mapping and Geographical Information System Hardware*, Photogrammetric Engineering and Remote Sensing. 39 (11), 1571-1576, 1988.

Department of Energy, *Summary Protocol: Identification-Characterization-Designation-Remedial Action-Certification*, Office of Terminal Waste Disposal and Remedial Action, Division of Remedial Projects, January, 1986.

Department of Energy, *A Manual for Implementing Residual Radioactive Material Guidelines*, prepared by Argonne National Laboratory and Los Alamos National Laboratory, (1987).

Department of Energy, *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance,* DOE/EH-0173T, January, 1991.

Department of Energy, DOE/Draft, *Environmental Implementation Guide for Radiological Survey Procedures*, prepared by Oak Ridge National Laboratories, November, 1992.

Environmental Protection Agency, CERCLA of 1976. Section 104(4), 1976.

Environmental Protection Agency, *Upgrading Environmental Radiation Data*, EPA 520/1-80-012, August,1980.

Environmental Protection Agency, 40CFR192. 1 & 2, Washington, DC, 1982.

Environmental Protection Agency, Federal Register 48(3), 590-904, 1983.

Environmental Protection Agency, *The CERCLA Compliance with Other Laws Manuals,* 1 &2, 1989a.

Environmental Protection Agency, *Methods for Evaluating the Attainment of Cleanup Standards,* 1, EPA 230/02-89-042, February 1989b.

Environmental Protection Agency, *GIS Technical Memorandum 3*, EPA/600/R-92/036, Washington, DC, 1992.

Environmental Protection Agency, *Interim Report of the Federal Facilities Environmental Restoration Dialogue Committee*, prepared by the EPA Restoration Dialogue Committee, Washington, DC, June 1993.

Ewing, B.D., *Pseudo-Kinematic GPS for the Surveyor,* GPS World, 1(5), 50-53, 1990.

Federal Register, *Standards for Remedial Actions at Inactive Uranium Processing Sites - Final Rule*, Washington, DC, 1983.

Gerdan, G.P., *Efficient Surveying with the Global Positioning System*, Surveying and Land Information Systems, 52(1), 34-37, 1992.

Gilbert, R.O., Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold, 1987.

Goad, C.C., *On the Move with GPS,* Point of Beginning, 14(4), 36-40, 1989.

Greene, J.R., *Accuracy Evaluation in Electro-Optical Distance Measuring Instrument,* Surveying and Mapping, 37(3), 247-250, 1977.

Hall, J.C., *Method of Formatting Data from a Mouse*, Patent #5,125,077, Redmond, WA, 1992.

Haug, M.D., *A Simplified Explanation of Doppler Positioning,* Surveying and Mapping, 40(1), 47-51, 1980.

Hern, J., GPS: Guide to the Next Utility, Sunnyvale, CA, Trimble Navigation , 1989.

Heuverman, H.R. and Senus, W.J., *Navstar Global Positioning System*, ASCE, Journal of the Surveying Engineering Division, 109(2), 73-78, 1983.

Hickey, C.R., Beck, W.L., Berger, J.D., Cotten, P.R., and Landis, M., *Instrumentation for Demonstrating Compliance with FUSRAP Guidelines,* Oak Ridge Associated Universities, Oak Ridge, TN, 1988..

Intel Corp., Embedded Microcontrollers and Processors. 1, 1992.

Johnson, C., Process Control Instrumentation Technology. 4th Ed., Prentice-Hall, 1993.

Kinsler, L. and Frey, A., Fundamentals of Acoustics. John Wiley and Sons, 1962.

Lafreniere, M.D., *Automation of a Positioning System for Indoor Environmental Surveys*, unpublished thesis, University of Florida, 1994.

Leick, A., GPS Satellite Surveying. John Wiley and Sons, 1990.

Little, C.A., Espegren, M.L., and Berven, B.A., Pr*ogress on the UMTRA Project: The Role of the Inclusion Survey Contractor,* Proceedings of Waste Management 1988, Tucson, AZ, March 1988.

Ludlum Corp., Model 2350 Operations Manual. Sweetwater, TX, 1992.

Knoll, G.F., Radiation Detection and Measurement. John Wiley and Sons, 1979.

Mann, B.J., *Radiological Surveys for Facility Decommissioning, Some Observations Based Upon the Shoreham Project.* Health Physics 39th Annual Meeting, San Francisco, CA, June 1994.

May, M.B., *Inertial Navigation and GPS,* GPS World, 4(6), 50-53, 1993.

Microsoft Corp., Microsoft Visual Basic-Programmers Guide. Redmond WA, 1994.

Myrick, T.E., Blair, M.S., Doane, R.W., and Goldsmith, W.A., *A Mobile Gamma-Ray Scanning System for Detecting Radiation Anomalies with Ra-226-Bearing Materials,* ORNL/TM-8475, Oak Ridge National Labs, 1982.

National Council on Radiation Protection and Measurements, *A Handbook of Radioactivity Measurement Procedures,* NCRP Report 58, 2nd Ed., February, 1985

National Instruments, DAQCard-700 User Manual. Austin, TX, 1994

Nelson, L.S., *The Shewhart Control Chart-Tests for Special Causes,* Journal of Quality Technology, 16(4), 237-239, 1984.

Nuclear Regulatory Commission, Regulatory Guide 1.86 (1974).

Nuclear Regulatory Commission, *Guidelines for Decontamination of Facilities and Equipment Prior to the Release for Unrestricted Use*, Washington, DC, 1982.

Nuclear Regulatory Commission, *Guidelines for Decontamination of Facilities*, U.S. Nuclear Commission, Washington, DC, 1987.

ORISE, Survey Procedures Manual for the Environmental Survey and Site Assessment Program (ESSAP). Oak Ridge, TN 1993.

ORISE, Quality Assurance Manual for ESSAP. Oak Ridge, TN, 1992.

ORNL, *Monitoring for Compliance with Decommissioning Termination Survey Criteria,* NUREG/CR-2082, Oak Ridge National Laboratory, Oak Ridge, TN, June 1981.

ORNL, *Residual Radioactive Contamination from Decommissioning*, NUREG/CR-5512, Oak Ridge National Laboratory, Oak Ridge, TN, January 1990.
Ott, L., An Introduction to Statistical Methods and Data Analysis. 3rd Ed., PWS-Kent, 1988.

Owens, J.C., *Optical Refractive Index of Air: Dependence on Pressure, Temperature and Composition*, Applied Optics, 6, 51-59, 1967.

Polaroid Corp., Ultrasonic Ranging Operations Manual. Cambridge, MA, 1983.

Policastro, G.V., *Use and Application of Specialized Techniques and Instrumentation for Decommissioning and Site Characterization*, presented at the Health Physics Mid-Year Meeting, Dearborn, MI, 1992.

Puttre, M., *Geographical Information Systems Add a New Dimension to Environmental Mapping*, Mechanical Engineering, 6, 54-59, 1992.

Querzola, B., *High Accuracy Distance Measurement by Two-Wavelength Laser Sources*, Applied Optics, 18, 3035-3047, 1979.

Roof, E.F., *Inertial Survey Systems,* ASCE Journal of the Surveying Engineering Division, 109(2), 116-120, 1983.

Rueger, J.M., Electronic Distance Measurement. 3rd Ed., Springer-Verlag, 1990.

Schleien, B., The Health Physics and Radiological Health Handbook. Scinta, Inc., 1992.

Stallones, L., Nuckols, J.R., and Berry, J.K., *Surveillance Around Hazardous Waste Sites: Geographic Information Systems and Reproductive Outcomes*, Environmental Research. 59, 81-92, 1992.

Texas Instruments, Linear Circuits Data Book, 1, 1989.

Treftz, W.H., *An Introduction to Inertial Positioning as Applied to Control and Land Surveying*, Surveying and Mapping, 41(1), 59-63, 1981.

Trimble Navigation, Inc., Technical Bulletin on PCMCIA GPS. 1994.

Wang, C.H., Willis, D.L., and Loveland, W.D., Radiotracer Methodology in the Biological, Environmental, and Physical Sciences, Prentice-Hall, Inc., 1975

Wendling, M.A., and Wade, C.D., *Rad Rover: GPS Visits the Hot Spots,* GPS World, 5, 21-26, 1994.

Wolf, P.R., and Brinker, R.C., Elementary Surveying. 9th Ed., Harper-Collins, 1994.

BIOGRAPHICAL SKETCH

I received my BS degree from Purdue University in 1983 and my MBA from Ball State University in 1989. I began working on my doctoral degree in 1990. My industrial experience includes two years as a maintenance technician with Wabash-Datatech in Paoli, Indiana, and five years as a manufacturing/plant engineer with Ford Motor Co.-EED in Bedford, Indiana. In addition, I have five years of teaching experience with Ball State University and Ohio University.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

W. Emmett Bolch

W. Emmett Bolch, Chairman
Professor of Environmental
Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Wm S Properzio

William S. Properzio
Associate Professor of
Environmental Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Eric R Allen

Eric R. Allen
Professor of Environmental
Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Thomas L. Crisman
Professor of Environmental
Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Bon A. Dewitt

Bon A. Dewitt
Assistant Professor of Civil
Engineering

This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements of the degree of Doctor of Philosophy.

May, 1995

Winfred M. Phillips
Dean, College of Engineering

Karen A. Holbrook
Dean, Graduate School